S.H.-1830

ELEMENTS

OF

ASTRONOMY

ILLUSTRATED BY THE MORE USEFUL

PROBLEMS ON THE GLOBES,

AND ADAPTED FOR

THE USE OF YOUNG PERSONS,

AND

THOSE UNVERSED IN MATHEMATICS,

WITH A

SET OF QUESTIONS FOR EXAMINATION.

By W. JEVONS Jun.

LONDON:
PRINTED FOR LONGMAN, REES, ORME, & CO.
PATERNOSTER-ROW;
AND ROWLAND HUNTER, ST. PAUL'S CHURCH-YARD; AND SOLD BY
G. & J. ROBINSON, W. GRAPEL, AND ROCKLIFF & DUCKWORTH,
LIVERPOOL.

1828.

LIVERPOOL:
PRINTED BY ROCKLIFF AND DUCKWORTH.

PREFACE.

The study of Astronomy holds very deservedly a prominent place in every system of liberal education, and yields in importance to few, if any, of the subjects which usually employ the attention of the young. So close, indeed, is its connexion with Geography, that the one cannot be studied altogether independently of the other; and if it be important to know something of the form and dimensions of the globe upon which we dwell, and of its various countries, inhabitants, and productions, it is surely of equal importance to know what station it holds in the great system of the universe, and how it is related to those magnificent orbs which so powerfully arrest our notice in the heavens. No branches of study are so important in education, as those which call into exercise the powers of observation, and direct those powers to their noblest field of exercise—*the great book of Nature*. In the

prevailing system of school education, this object is by no means regarded with the attention which its importance deserves. Learning is made too much a business of rote. The memory is too much cultivated at the expense of the powers of observation and reasoning, and the study of *words* is more attended to than the study of *things*. Books are the only sources of knowledge to which the attention of the young is much directed, though certainly they are of little use except as they serve to stimulate or direct them to the exercise of their own observation. Now Astronomy, like every other branch of natural science, is a study of such kind, that though it may be greatly aided by books, it cannot be pursued with any success by means of books alone. The heavens and the heavenly bodies themselves must be observed with assiduity and care, and what is learnt from books must be verified by the evidence of sense, or the study will be found not only destitute of interest or benefit, but wholly incomprehensible in many of its most important parts. Too often, indeed, the attempt is made to teach Astronomy as if it were a science that could be learnt sufficiently in the school-room or the closet, and the ill-fated learner is doomed to task his memory

with a number of strange and difficult terms, to which he can attach no clear ideas, or led through a dull routine of problems on the globes, which he learns to perform according to the directions given, without at all understanding the principles upon which they are founded. Numerous as are the treatises on this important branch of education, few of them are written according to that *method of analysis* which alone is calculated to render the subject interesting and intelligible. Instead of leading the learner on by degrees from what is easy to what is difficult; instead of directing his attention in the first instance to actual appearances, and placing him in the situation of the first observers of the heavens,—they launch at once into the grand discoveries of modern Astronomy, which he is not as yet prepared to appreciate, or enter into a miscellaneous series of dry definitions, which can only serve to disgust and repel. It was from observing these defects in the common elementary treatises on Astronomy, that the Author, who is engaged in the business of private tuition, was led to draw up for the use of his pupils a treatise more accordant with his own ideas. This work he used for some time in manuscript, but finding occasion for a

greater number of copies than he could thus conveniently obtain, he had recourse to the press, which naturally led to the thought of publication. He ventures, accordingly, to publish his little work, which lays claim to no other merit than that of simplifying and reducing to the capacity of the young a highly interesting and important subject, in the hope that it may meet the views and wishes of others who are engaged in the same pursuits, and who have felt the same want of a suitable help to their instructions.

Alfred Street, Liverpool,
June, 1828.

ERRATA.

P. 24. l. 7. *after* NESQ *insert* Fig. 4.

P. 29. l. 12. *for* plane of the horizon, *read* plane of the celestial horizon.

P. 145. l. 14. *for* the *read* they.

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INTRODUCTION.

OF THE OBJECT AND USE OF ASTRONOMY.

ASTRONOMY is that science which treats of the heavenly bodies, describing their motions, explaining their appearances, and ascertaining their magnitudes, distances, and relative situation. The name is derived from two Greek words, *αστρον* and *νομος*, which signify the law of the heavenly bodies.

In point both of interest and usefulness, Astronomy may fairly challenge competition with any of the sciences. It is interesting from the very grandeur of the objects to which it relates, and from the sublime views which it unfolds of the vastness and magnificence of the universe. And even if it served no other purpose than the gratification of a liberal curiosity, it would on this ground alone well deserve our attention; for what person, imbued with the smallest love of knowledge, and worthy of the title of a rational being, can willingly remain in ignorance of the causes which operate in producing those grand changes and move-

ments of nature, so important to the welfare of the human race—the alternations of day and night, and the beautiful and grateful succession of the seasons? Who can regard with unadmiring and uninquisitive view the sublime spectacle of the nocturnal heavens; the devious courses of the planets; the changeful aspect of the moon; or the insufferable splendour of the orb of day,—

> - - "Best image here below
> Of its Creator, ever pouring wide,
> From world to world, the vital ocean round?"

Dull indeed must that mind be, and dead to all the charms of knowledge, which does not burn with eager curiosity to learn whatever may be known respecting these great objects. If, however, purposes of more substantial utility be sought for, Astronomy is by no means wanting in this recommendation; for it has materially contributed to the improvement of some of the most important arts of life, and has a close connexion with many unquestionably useful branches of knowledge. By its aid the navigator directs his course through the trackless ocean, and commerce, thus extended to the remotest regions of the globe, enriches us with the productions of every clime, and forms a bond of alliance, to their mutual advantage, between nations which would otherwise have been ignorant of each other's existence. By its assistance the earth has been measured, and the geographer is furnished with an unerring method of ascertaining the exact

situation and extent of the countries which he delineates or describes. It furnishes the only certain and invariable standard for the computation of time, and history is indebted to it for the recovery of many important dates, which the imperfect annals of remote antiquity had left uncertain. Nor should it be forgotten, that the light of Astronomy has utterly dispelled those groundless terrors which the more extraordinary phænomena of the heavens were formerly wont to inspire; and comets and eclipses are now no longer looked upon, except among barbarous and unenlightened nations, as tokens of divine anger, or harbingers of war and pestilence. The same cause has also contributed to bring into deserved discredit that vain science which pretended to read the destinies of man in the aspects of the planets. But of all the uses and advantages of Astronomy, the highest and most important, and that which strongly recommends it to the attention of all without exception, consists in the striking evidence which it affords of the existence and perfections of the Great Supreme. The grand spectacle of the heavens has ever been considered as presenting the most powerful impulse to rational devotion, and the most striking lesson of natural religion. It is here that we discover the highest wonders of creation, and observe the clearest display of that admirable order and contrivance which so plainly evince the superintendence of a great designing Cause. "The heavens," said the Psalmist, "declare the glory of God, and the firmament showeth his handy-work:" and who that

has once held converse with the skies, but will feel the full truth and force of the pious sentiment? So clear, indeed, is the evidence which this science affords of the existence and attributes of God, and so just and enlarged the ideas which it suggests of his character, that I can hardly consider it as any exaggeration to assert, in the words of the poet, that

> "An undevout Astronomer is mad."
>
> *Young's Night Thoughts.*

CHAPTER I.

DESCRIPTION OF THE MORE OBVIOUS APPEARANCES OF THE HEAVENS.

THE first step in the study of Astronomy is to observe the general aspect and more obvious appearances of the heavens, and then to consider how these appearances may be accounted for. The student of this science, instead of entering at once into those grand views of the structure of the universe which have been unfolded by modern discoveries, should endeavour to place himself, as much as possible, in the situation of the first observers of the heavens, and consider what facts they had upon which to reason, and what it was that they ascertained or conjectured.

On turning our attention to the heavens, we find ourselves placed in the centre of what appears a vast dome or concave, bending over a plane of unlimited extent. By night this dome or concave appears beautifully studded with countless specks of light, and though they disappear at the approach of the great luminary of day, yet from their gradual disappearance and gradual reappearance, it is readily and naturally inferred that they would be always visible, were it not for the brighter splendour which overpowers their feeble ray. Nor is it much less obvious, after a little

observation, that this concave frame of stars extends beneath us as well as above us; for it seems to revolve like a wheel upon its axis, and presents successive portions of its surface to our view. Observing this revolution more attentively, we find a remarkable difference in the motions of the stars according to the direction in which we look. Looking in one direction, towards the south, we observe some stars which just make their appearance above the horizon, attain a very small elevation, and then descend, and shortly disappear. A little further from the south, we find the stars describing a larger arc, and appearing for a longer period. But on turning our view to the north, we observe stars which are constantly visible in the absence of the sun, performing their circuits entirely above the horizon, in circles one within another, till we arrive at a star which, being itself stationary, is the centre of the revolutions of all the rest. This remarkable star must doubtless have attracted at a very early period the notice of mankind, and the discovery of it may be considered as the first step in the science of Astronomy.* It is not, strictly speaking, motionless; for it describes a very small circle round a point not marked exactly by any star. This point, the exact centre of the celestial motions, is called the *Pole*, and the star which nearly marks its situation, is called the *Pole-star*.

* The Phœnicians are said to have used this star as a guide to direct their course at sea.—See Bossut's History of Mathematics, by Bonnycastle, p. 90; Rutherford's Ancient History, vol. i. p. 162.

By observations made in travelling northward or southward, it is soon found that the pole is more or less elevated according to the part of the earth from which it is viewed. Thus, in the north of Scotland it appears considerably higher than at London; and in Lapland it is almost overhead. We see it more elevated than the inhabitants of Spain; and they see it more elevated than the inhabitants of Barbary. If we travelled continually southwards, we should see the pole-star gradually sinking lower and lower, and at length disappearing below the horizon. But then another motionless point or pole would be discovered in the opposite direction, (though not distinguished by any remarkable star,) and another hemisphere of stars would appear performing in like manner their circuits round it.

The general appearance, therefore, of the starry heavens, is that of a vast concave sphere turning round two fixed points diametrically opposite to one another, which points are called the *Poles* of the heavens, and distinguished by the names of *North* and *South*. It is represented by the artificial Celestial Globe, with which the learner should here be made acquainted. It is a sphere revolving on an axis, and containing on its surface a map or plan of the stars, according to their true relative situation; but differing from the real sphere of the heavens in this respect, that it represents the stars on a *convex* surface, which we look upon *externally*, whereas we are placed *within* the real sphere, and view the stars on its apparent *concave* surface. The

learner has only to imagine the celestial globe considerably enlarged in its dimensions, and made transparent, and to suppose his eye placed in the centre looking upwards; he will then have in idea an exact facsimile of the starry heavens. The wooden circle which surrounds the globe represents the *Horizon*,* which bounds our view of the heavens. That part of the globe which is above the circle represents the *visible hemisphere;* that part which is below, the *invisible hemisphere.* The central point of the former, or that point in the real heavens which is immediately above the head of the observer, is called the *Zenith.* The point directly opposite to this in the invisible hemisphere, is called the *Nadir.* If the pole of the globe be elevated in the same proportion as the real pole of the heavens in the place where the observer is situated, it will then represent exactly that aspect of the heavens which is there presented to him. And if the globe be made to revolve from the side marked East, towards that marked West, it will represent the motion of the celestial sphere.

The learner will observe that the surface of the celestial globe is covered with a variety of figures of men, women, animals, and other objects. This is a contrivance invented in very early times, for facilitating the knowledge of the stars. The author, time, and place of this invention, are lost in the darkness of

* This word is derived from the Greek verb ὁρίζω, which signifies *to bound* or *limit.*

antiquity; but there is little doubt that it first arose from the fancied resemblance of certain groups of stars to the figures from which they have derived their names. In the fine climate of Chaldæa, where Astronomy was probably first cultivated, and among pastoral tribes who had often no other roof above them than the canopy of heaven, we may well suppose it was a common and favourite employment to gaze on the cloudless firmament, and to exercise their fancy and ingenuity in tracing these resemblances, some of which are sufficiently obvious. Some knowledge of these groups or constellations is indispensable to the student of Astronomy, but is only to be acquired by a careful observation of the heavens themselves, assisted either by a teacher or by a celestial globe. The more remarkable constellations, and those which the student will most easily discover, are Ursa Major, Ursa Minor, which includes the polar star, Orion, Taurus, including the two remarkable groups called the Hyades and the Pleiades, Gemini, Leo, Auriga, Bootes, Corona Borealis, Cassiopeia, &c.

Besides being distributed into constellations, the stars are further distinguished according to their different size or brilliance, there being seven magnitudes denoted on the celestial globe by their respective figures. Most of the stars of the first magnitude, together with some of the second, have received particular names, and with the names and situation of these, the student should by all means render himself familiar. The other stars are distinguished on the globe by the

letters of the Greek alphabet, which are called Bayer's characters, from the philosopher who first employed them. Their use is to designate particular stars, the name of the constellation pointing out the region of the sphere where any star is situated, and the letter specifying what particular star of that constellation is referred to; as *α Arietis*, *γ Draconis*, *β Lyræ*.

CHAPTER II.

CONTAINING DEFINITIONS OF SOME OF THE MORE REMARKABLE POINTS AND CIRCLES OF THE CELESTIAL SPHERE.

The celestial globe, besides presenting this general plan of the stars, has marked upon it several points and circles, the use of which I now proceed to explain.

From observing the manner in which the heavenly sphere revolves, nothing was more natural and obvious than to notice those four remarkable points on the horizon, which are called the *Cardinal Points*. The direction of the poles having first pointed out the *North* and *South* points of the horizon, it was natural to distinguish the two intermediate points, the one on that side of the horizon *from* which the motion of the heavens proceeds, called the *East*; the other on that

side *towards* which the motion proceeds, called the *West*. The accuracy of modern science has led to more minute subdivisions, which may easily be learned by inspecting the wooden horizon of the globe, or a mariner's compass.

The same observation of the position and revolution of the heavens, suggests not less naturally the imaginary division of the sphere by two great circles passing through the cardinal points, and crossing each other at right angles. These imaginary circles are the Equator and the Meridian.

The *Equator*, or *Equinoctial*, is a circle drawn through the east and west points, parallel with the circuits of the stars, and every where equidistant from the poles. It divides the sphere into two equal parts, which are distinguished by the names of the Northern Hemisphere, and the Southern Hemisphere. This was the first great circle which the ancient astronomers imagined, and by means of which they pointed out the places of the stars.

The *Meridian* is a circle drawn at right angles to the former, connecting the north and south points, and passing through the Zenith. It divides the heavenly sphere into the Eastern Hemisphere and the Western Hemisphere. It likewise intersects the circuits of the stars exactly in the middle point, so that when any star is upon the meridian, it is then equally distant from its rising and its setting point, and has attained its greatest elevation. It is then said to *culminate*, from the Latin word *culmen*, the top. In the same

manner the sun's daily course is equally divided by the meridian, so that he is always upon this line at noon-day. Hence the name Meridian, from *Meridies*, the Latin word for noon. It is represented on the artificial globe by the brazen circle in which the globe is hung. A straight line drawn upon a horizontal plane in the direction of the meridian, or pointing north and south, is called a *meridian line;* and since it is indispensable as the basis of all astronomical observations, and often necessary even for some of the common purposes of life, to ascertain this line with accuracy, I shall here subjoin the method of doing it.

PROBLEM.

To draw a Meridian Line upon a Horizontal Plane, and to determine the four Cardinal Points.

Describe several concentric circles on a horizontal plane, and in the centre fix a straight wire exactly perpendicular to the plane. Watch the shadow of the wire in the forenoon, and mark when its extremity touches any one of the circles. Then wait till the afternoon, and mark when the extremity of the shadow again touches the same circle. Bisect the arc of the circle contained between these two points, and a line drawn from the point of bisection to the centre of the circle will be the meridian line required. For the two shadows being of equal length, proves that the sun had the same altitude at the two periods when the marks were made; and as the sun's altitude uniformly

increases till he comes to the meridian, and uniformly decreases afterwards, it follows, that at those two periods he was exactly at the same distance from the meridian, though on different sides, and that the meridian must lie exactly midway between the sun's place eastward in the morning, when the first mark was made, and the sun's place westward in the afternoon, when the second mark was made. It is scarcely necessary to add, that if a line be drawn at right angles across the meridian thus found, that line will point due east and west, and thus the four cardinal points will be ascertained.

Whether this method of finding the meridian was the method practised by the earliest astronomers, it is impossible to say, as we have no records to inform us. But that some method of doing it with accuracy was known at a very early period to the Egyptians, is proved by the fact that the pyramids are built with their four sides facing the four cardinal points.

The horizon, the equator, and the meridian, are each divided into 360 equal parts, called degrees, for the purpose of more accurately stating such parts of them as we have occasion to mention. History does not inform us by whom or on what grounds this particular division was adopted; but the following is the most probable explanation: "The month, at first, was supposed to be finished in thirty days; and afterwards, when the motions of the moon came to be compared with and adjusted to the motion of the sun, twelve of these were thought to correspond exactly with the sun's

annual course; and therefore, since $30 \times 12 = 360$, this, probably, became the reason why 360 degrees, or parts, were made the common measure of all circles in general."*

CHAPTER III.

OF ALTITUDE, AZIMUTH, AND AMPLITUDE.

HAVING already had occasion to speak of the altitude of the pole, and the altitude of the sun, and the distance of the sun from the meridian, it becomes necessary to explain more fully the manner in which these distances are estimated and ascertained.

The *Altitude* of a heavenly body is its distance from the nearest point of the horizon, which nearest point is ascertained by a perpendicular from the heavenly body to the horizon. If this perpendicular be extended upwards, it will necessarily pass through the zenith; and being extended round the sphere, it will form what is called a *Vertical Circle*. The meridian is the only one of these circles represented on the artificial sphere, but they may be imagined to be drawn to any point of the horizon; and the instrument called the Quadrant of Altitude, when fixed to the zenith of the globe,

* Costard's History of Astronomy, p. 44.

will represent any vertical circle whatsoever. On these imaginary circles altitudes are estimated; and for this purpose that portion of them which extends from the horizon to the zenith, being a quarter of the whole circle, is divided into 90 equal parts or degrees, that number being a fourth part of 360. The following is the simplest method of ascertaining the altitude of a heavenly body.

PROBLEM.

To ascertain the Altitude of a Heavenly Body.

The instrument OAC (Fig. 1.) is a quadrant or quarter of a circle, having its arc AC divided into 90 degrees counted from A to C, and a plumb line OP suspended from the centre. The edge of the quadrant CO, (which is furnished with sights,) being directed to the heavenly body S, the plumb line will indicate its altitude on the arc AC, for the angle of altitude SOH is equal to its vertical angle ROC; and as AOC and POR are equal, being right angles, if the common part POC be taken away, the remainders AOP and COR will be equal; consequently AOP is always equal to the angle of altitude SOH.

The *Azimuth* of a heavenly body is its distance from the meridian. This distance is ascertained by observing how many degrees of the horizon are contained between a vertical circle passing through the heavenly body and the north or south point. The wooden horizon of the artificial sphere is graduated for this purpose

from the north and south points towards the east and west points.

The *Amplitude* of any heavenly body is its distance from the east point when rising, or from the west when setting. Degrees of amplitude also are marked in a distinct circle on the horizon of the celestial globe, the numbers commencing at the east and west points. But in the real heavens both azimuth and amplitude can only be ascertained by means of an instrument of a more complex construction than that already described.

Having now taken a general survey of some of the more obvious appearances of the heavens, and noticed certain points and circles which are found useful by astronomers in describing the situation of the heavenly bodies; before proceeding to state other more particular appearances, we may here enter upon some inquiries, for which the facts already mentioned sufficiently prepare us. The first of these inquiries relates to the figure and magnitude of the earth; the next to the cause of the apparent revolution of the heavens.

CHAPTER IV.

OF THE FIGURE AND MAGNITUDE OF THE EARTH.

To all appearance the earth is a vast plain, extended without limit on every side; and such was very naturally the idea universally entertained respecting it by mankind in the earliest ages; and which prevails even at the present day among the ignorant and barbarous portion of mankind.* We cannot with certainty determine when or by whom it was discovered that the earth is spherical; but we are informed that this doctrine was taught by Anaximander, who flourished about 550 years before Christ;† and if it be true, as Herodotus relates, that Thales, the friend and preceptor of

* "Before this system" (the system of concentric spheres) "was taught in the world, the earth was regarded as, what it appears to the eye, a vast, rough, and irregular plane, the basis and foundation of the universe, surrounded on all sides by the ocean, and whose roots extended themselves through the whole of that infinite depth which is below it. The sky was considered as a solid hemisphere, which covered the earth, and united with the ocean at the extremity of the horizon. The sun, the moon, and all the heavenly bodies rose out of the eastern, climbed up the convex side of the heavens, and descended again into the western ocean, and from thence, by some subterraneous passages, returned to their first chambers in the east."—Smith's History of Astronomy, in his Philosophical Essays, p. 32.

† See the life of Anaximander, by Diogenes Laërtius.

Anaximander, predicted eclipses, the doctrine cannot have been unknown to him. The appearances, indeed, presented by the heavens are so inexplicable on the supposition of the earth being a plane, that its true form was probably conjectured by astronomers before the time of Thales, (A. C. 600.) If the earth were a plane, its inhabitants, wherever situated upon its surface, would have the same view of the celestial concave, and it would be impossible, by travelling ever so far in any direction, to alter our horizon. The sun also would rise, set, and come to the meridian at the same instant to all places of the earth. This, however, is contrary to fact; for by travelling northward or southward, the pole star, as we have observed, is elevated or depressed; and by travelling eastward or westward, the time of day is altered. When it is noon here, it is one o'clock to places situated a certain distance eastward of us; and eleven o'clock to places situated at the same distance westward. These facts alone are sufficient to prove that the earth is spherical, for it is only on that supposition that they can be explained. For let HZON, (Fig. 2.) represent the apparent sphere of the heavens, and, according to the first ideas of mankind, let AB be the supposed plane of the earth, situated in the midst of the concave, and surrounded by an immense ocean. It is evident that a spectator placed in any part of the plane AB can have no other horizon than HO, and see no other part of the celestial sphere than what is above that plane. Let A and B be two spectators situated north and south

of each other, the pole P must appear to them equally elevated. Or if they be supposed to be situated east and west of each other, the sun revolving in the circle HZON would at the same instant make its appearance to both at H, be on the meridian to both at Z, and set to both at O. But let the earth be supposed spherical, as represented in Fig. 3, and then it will be evident that a spectator at A will have the horizon BC, and view the part BDC of the celestial sphere; while another spectator at E will have DF for his horizon, and DCF for his visible hemisphere. Supposing D to be the pole of the heavens, the spectator E will scarcely see it, because it will be just on the verge of his horizon; but if he travel towards A, that is, northwards, his view will extend further and further beyond the point D, and the pole will consequently appear to rise higher and higher above his horizon; and if he could reach the point A, he would see the pole directly above his head. Supposing, again, that the circle BDCF represent, not the meridian, but the sun's apparent diurnal course, and that the spectators A and E are situated east and west of one another: the sun being at D will appear on the meridian to the spectator A, when it will be only rising to the spectator E. At C it will be setting to A, and on the meridian to E. At F it will be setting to E at the time which A calls midnight, and at B it will be rising to A at the time which C calls midnight. This alone is a sufficient proof that the figure of the earth is spherical; but the following facts may be mentioned in confirmation of the argument.

Several navigators have sailed round the globe. The first person who made this attempt was Magellan, who sailed from Seville, in Spain, on the 10th of August, 1519. He did not himself live to complete the undertaking, having unfortunately been slain in a skirmish with the natives of one of the Philippine islands, where he had touched; but his crew continued their voyage in a westerly direction, and arrived in Spain in September, 1522. The circumnavigation of the globe has been since performed by Sir F. Drake, Lord Anson, Captain Cook, and others.

The roundness of the earth is sometimes evident even to the senses; for the tops of mountains are often seen far off at sea, when their bases and the neighbouring shores are hidden by the intervening convexity.*

* A remarkable instance of this is related in the following extract from Captain Basil Hall's Journal: "On the 9th of June we sailed from Arica, and steered along shore to the north-west. In the evening of that day we had a fine view of the Cordillera, or highest ridge of the mountains, not less than 80 or 100 miles off. It was only when the ship was at a considerable distance from the shore that the higher Andes came in sight; for when near to it, the lower ranges, themselves of great height, intercepted the remote view; but when we stretched off 30 or 40 miles, these intermediate ridges sunk into insignificance, while the chain of snowy peaks rose in great magnificence behind them. It sometimes even happened, that the lower ranges, which had entirely obstructed the view of the Cordillera when viewed at no great distance from the coast, were actually sunk below the horizon by the curvature of the earth, when the distant ridges were still distinctly in sight, and more magnificent than ever."—Captain Basil Hall's Journal, vol. i. p. 196.

And, lastly, in eclipses of the moon, which, as will hereafter appear, are caused by the moon's entering into the earth's shadow, that shadow is always circular, and therefore the body which casts it must be a sphere.

The same observations which suggested the true figure of the earth, would also suggest a method of ascertaining its bulk; for though it is obviously impossible to measure the whole circumference, yet the measurement of a small portion of the circumference will equally well answer the purpose, provided it be known how often that portion is contained in the whole. Supposing, for instance, the circumference of the earth divided, like that of the heavens, into 360 equal parts, or degrees, and that we could ascertain the length of one of these in English miles; that length being multiplied by 360, would give the dimensions of the whole circumference. Now, the length of a degree is easily ascertained, by merely observing that change which takes place in the position of the heavens, whenever we travel northwards or southwards. I measure, for instance, the altitude of the pole at the place where I reside; I then travel northward, continuing my observations, until I find that its altitude is increased one degree; and by this I know that I have traversed one degree, or 1-360th part of the earth's circumference. This distance being measured will enable me to ascertain by an easy calculation the entire circumference. The first recorded attempt of this kind was made by a Greek philosopher, of the name of Eratosthenes, who

flourished 230 years before the Christian era. Being informed that, at the city of Syene in Upper Egypt, the sun, at the time of the summer solstice, was vertical, so as to illumine the bottom of a deep perpendicular well, he carefully ascertained its altitude at the same season at Alexandria in Lower Egypt, and found it to be 1-50th of the whole circumference, or $7\frac{1}{5}$ degrees, less. Hence he inferred, that the distance between Alexandria and Syene was 1-50th of the whole circumference of the earth. On measuring this distance, it was found to be 5000 stadia, which gave 250,000 stadia for the length of the entire circumference. Our uncertainty respecting the precise length of the measure which he employed, renders it impossible to determine the accuracy of this estimate. Several attempts of a similar kind were made by succeeding astronomers; but the first person who solved this problem satisfactorily, was our countryman, Mr. Richard Norwood, (A. D. 1635,) who, by measuring the distance between York and London, which he estimated to contain about $2\frac{1}{4}$ degrees, found the length of one degree to be $69\frac{1}{2}$ English miles. This being multiplied by 360, gives 25,020 miles for the entire circumference of the earth. Later and more accurate measurements, however, have shown that Norwood's estimate of the length of a degree somewhat exceeds the truth, and the circumference of the earth, according to the most approved estimate, is now reduced to 24,855 miles; whence the diameter is found, by an easy calculation, to be about 7911 miles.

Before leaving this subject, it is proper to observe, that when we say the earth is spherical, the assertion must not be understood in the strictest sense; for, from the accurate observations of modern astronomers, it has been found to be not a perfect sphere, but a spheroid, that is, somewhat of the shape of an orange, though not differing in the same degree from a perfect sphere. This fact was first suggested to Sir Isaac Newton, by observations made on pendulums, which being fitted to beat seconds in the latitudes of Paris and London, were found to move slower as they approached the equator; which could only be owing, he thought, to their being further removed from the centre of the earth, and consequently acted upon by a smaller power of attraction, at the equator than nearer the poles. This opinion was confirmed by an experiment made under the auspices of Louis XIV. king of France, in the year 1735, when two companies of astronomers were sent from France to measure arcs of the meridian in different parts of the world, and it was found that the degree measured by one company in Lapland within the polar circle, was somewhat larger than that measured by the other company under the equator in South America.* This proved the truth of Sir I. Newton's conjecture that the earth is flattened at the poles. For a degree being a 360th part of a circle, it is evident that the absolute length of a degree will be in proportion to the dimensions of the circle of

* The difference was found to be 669 toises, equal to 1426 yards.

which it is a part, and that the larger the circle, the longer will be the degree. In the same circle every degree is of the same length; but in an ellipse, such as a meridian must be, if the earth be a spheroid, the length of a degree must vary according to the different curvature of the parts where it is taken. For let the ellipse NESQ represent a meridian of the earth, N and S being the poles, and EQ the equator. It is evident, then, that the part AB about the equator, and the part CD about the pole, have different degrees of curvature, and may be considered as portions of different circles. The part AB about the equator, may be considered as a portion of the small circle ABF, while the part CD about the pole is a part of the large circle CDG. A degree, therefore, in the part CD, must be longer than a degree in the part AB, agreeably to what is found to be the fact. The earth is, therefore, a spheroid. It is found, however, by calculation, that the equatorial diameter exceeds the polar only by about 24 miles.* This difference is so very inconsiderable compared with the whole diameter of the earth, that no material error can arise from overlooking it altogether. An artificial globe representing in just proportion the true figure of the earth, would not perceptibly differ from a perfect sphere.

* See Malte Brun's Geography, vol. i, p. 58, 59.

CHAPTER V.

OF THE DIURNAL MOTION OF THE EARTH.

THAT the earth is fixed immovably in the centre of the universe, and that all the heavenly bodies revolve round it in 24 hours, seems to be so plainly the information of the senses, that it continued for a long time the universal belief, even after the doctrine of the earth's spherical figure had become fully established and generally acknowledged. History does not inform us who first advanced the bold doctrine of the earth's motion;* but when astronomers had begun to entertain more just ideas of the superior magnitude of the sun, and the immense distance of the fixed stars, it seemed evidently unreasonable to suppose that bodies so vast and so distant should be whirled so rapidly round this comparatively minute globe, when the same appearances may be so easily explained by ascribing this diurnal motion to the earth itself. The sun is now known to be a million times larger than the earth, and its distance being 95,000,000 miles, if it revolve round the earth in 24 hours, it must move at the pro-

* Cicero informs us that this doctrine was maintained by one Hicetas, or Nicetas, of Syracuse, of whom nothing more is known. And some, he adds, think that Plato, in his Timæus, asserts the same, though in more obscure terms.—Vide Academ. Quæstion. lib. iv. cap. 39.

digious rate of more than 400,000 miles a minute. What, then, must be the rapidity, on this supposition, of the fixed stars, whose remoteness from us is beyond all calculation! The revolution, in fact, of a larger round a smaller body, is contrary to the known laws of matter and motion; for no body in nature can act upon another, without being itself acted upon by a force proportioned to the quantity of matter contained in that other; and consequently any two bodies being placed in free space within each other's influence, however different in mass or weight, must both revolve round their *common centre of gravity*, the distance of which from the two bodies is necessarily in the inverse proportion of their weights. To render this familiar, let us suppose that we have two balls of the same materials, connected together by a straight rod or wire. If the balls be of equal weight, they may evidently be suspended in a horizontal position by a string fastened exactly in the middle of the rod, which is the balancing point or centre of gravity; and if in in this situation one of them receive an impulse, they will both revolve in the same circle round that point. But if they be of unequal weight, this balancing point or centre of gravity, by which they may be thus suspended and whirled, will be nearer to the heavier ball, and just as much nearer as that heavier ball exceeds the lighter in weight. Being suspended from that point, and set in motion, they will both revolve round it, but in unequal circles, the circles being inversely as the weights. This simple experiment ex-

actly represents the law which governs the revolution of the heavenly bodies; and hence it may be understood that it is physically impossible for a larger body to revolve round a smaller, which is stationary. On these grounds it is now universally admitted that the diurnal revolution of the heavens is only an apparent motion, produced by the real revolution of the earth in the contrary direction.

If it be asked, "why are we insensible of this motion?"—a variety of similar facts, with which every one is familiar, may be appealed to; such as the apparent motion of objects on the road-side to a person travelling swiftly in a close carriage, or of the banks of a river as seen from the cabin of a vessel sailing along it. The situation of an aëronaut in his balloon, who is quite insensible of his rapid motion, presents a still more exact parallel.

In a manner equally easy may another objection be removed, which was once urged with great confidence against the doctrine of the earth's motion. It was contended that, if the earth moved eastward on its axis, an arrow shot directly upwards would not fall, as it does, in the same place, but considerably to the west, the earth, during its flight, having moved from under it towards the east. But this objection is founded in ignorance of the laws of moving forces; for it is well known that, if a body be projected from another body in motion, it will not move exactly in the direction of the projecting force, but, while acted upon by that force, will partake also of its previous

motion. Thus a person leaping from a carriage in rapid motion, finds himself, when he reaches the ground, thrown forward violently in the direction in which he was going; and a stone dropped from the top of a mast, while the ship is under sail, falls not nearer the stern, but exactly at the foot of the mast.

CHAPTER VI.

OF THE TERRESTRIAL GLOBE, AND OF LATITUDE AND LONGITUDE.

THE doctrine of the earth's spherical figure and diurnal rotation being established, the learner may now be introduced with advantage to the knowledge of the Terrestrial Globe, which must be considered first in its relations with the Celestial. For this purpose let the former be imagined as diminished to a point, and placed within the latter exactly in the centre. As the apparent rotation of the celestial sphere is caused by the real rotation of the earth, it is obvious that the position of the two spheres must correspond, the poles of the earth being immediately under the poles of the heavens, and the equator of the earth under the equator of the heavens. Let the terrestrial globe be supposed to be so placed within the celestial, and let a motion be given to it from the west to-

wards the east, and we shall then have a correct representation of the relative situation of the earth and the heavens.

The terrestrial globe is furnished, like the celestial, with an horizon and a meridian. But the horizon, considered in its proper sense, as the circle which bounds our view, belongs more properly to the celestial than to the terrestrial globe; for it is needless to observe, that though we can see a hemisphere of the heavens, our view cannot extend over a hemisphere of the earth. On the terrestrial globe it merely represents the *plane of the horizon*, or that plane which, being extended to the heavens, would separate the visible from the invisible hemisphere. It is of use, however, on the terrestrial globe, because this globe often serves the purpose of the celestial.

Here we may take occasion to explain the distinction which is usually made by writers on these subjects, between the *sensible* and the *rational* horizon. The *sensible horizon*, as the name implies, is that circle which actually bounds our view, and which, as respects the earth, extends not more than a few miles around us. The *rational horizon* is a circle or plane parallel to the former, which passes through the centre of the earth, and divides both the earth and the celestial sphere into two equal parts. But it is to be observed, that, with respect to the heavenly bodies, the sensible and the rational horizon, are the same, or so nearly the same, that the difference may be disregarded. This is owing to the vast distance of the heavenly

bodies, and the comparative minuteness of the earth. For let the small circle A, Fig. 5, represent the earth, and DFE a portion of the heavenly concave: the line BC will then represent the sensible horizon of an observer at A, and the line DE drawn through the centre, his rational horizon, the distance between them being equal to the earth's semidiameter. It is evident that the plane BC divides the celestial sphere into two unequal portions, and that only the smaller of these is visible to us. But as the earth itself is a mere point compared with the immense sphere of our vision, the difference between the hemisphere DFE, and the smaller segment BFC, actually visible to us, is too small to be perceptible.

The Equator of the earth corresponds exactly with the equator of the heavens, being an imaginary circle every where equidistant from the two poles, and dividing the earth into two hemispheres, the northern and the southern.

Distance from the equator measured directly towards the north or south, is called *Latitude*, and is estimated in degrees. The distance of either pole from the equator, being a fourth part of the whole circumference, contains 90 degrees, which is therefore the utmost extreme of latitude.

The circles drawn parallel to the equator at the distance of every ten degrees, are called Parallels of Latitude.

Any line drawn at right angles to the equator, and extended to each pole, is called a Meridian, because

it shows what places have noon at the same time. But only 24 lines of this kind are actually drawn upon the globe, corresponding to the 24 hours of the day. The space between each meridian contains 15 degrees, for $360 \div 24 = 15$; and over this space the sun moves, or appears to move, in an hour. When therefore it is noon to places under any meridian, it is an hour past noon, or one o'clock, to places under the next meridian *eastward*, and an hour before noon, or 11 o'clock, to places under the next meridian *westward;* and so in proportion for a greater distance. Hence it is, that, by travelling *westward*, we *protract* the interval between noon and noon, and by travelling *eastward*, we *shorten* it; and if two persons should set out from the same place, the one in a westward, and the other in an eastward direction, and make the circuit of the globe, at the end of their journey the reckoning of the former would be found a day behind the true reckoning, and that of the latter a day before it.

Distance eastward or westward reckoned in degrees is called *Longitude.* But where to *begin* the reckoning, is a matter of purely arbitrary appointment, and different nations have adopted different meridians as the first, each reckoning in general from the meridian of its own capital. On English maps and globes, the first meridian is that of Greenwich, on account of the Royal Observatory being situated at that place.

The brazen circle in which the terrestrial globe is hung, represents the meridian of any place that is brought under it. It is chiefly used for ascertaining

the latitude of places, for which purpose it is graduated or divided into degrees, the degrees being numbered on one side from the equator towards the poles; so that by bringing any place to the meridian on that side on which it is so numbered, its latitude will be found immediately over.

The longitude of places on the globe is ascertained by means of the equator, which is also divided into 360 degrees; and these are counted from the first meridian eastward and westward to the meridian directly opposite, where east and west longitude meet. To ascertain the longitude of any place upon the globe, bring it to the brazen meridian, and observe the degree of the equator which the meridian intersects.

It will now be readily understood what different aspects of the celestial sphere are presented to different inhabitants of the earth. Those who live at the equator, will have the equator of the heavens exactly overhead, and the poles in their horizon. The stars will revolve in circles perpendicular to the horizon, and all of them will rise and set once in 24 hours. This aspect of the heavens is called a *right sphere.*

An observer situated at the pole of the earth will have the corresponding celestial pole in his zenith, and the opposite pole in his nadir. The equator will coincide with the horizon, and the stars will revolve in circles parallel to the horizon, one hemisphere being always visible, and the opposite hemisphere invisible. This aspect of the heavens is called a *parallel sphere.*

An observer situated at any place between the equa-

tor and the pole, will have one pole elevated and the other depressed, and the heavenly bodies will appear to move in circles oblique to the horizon. This aspect of the heavens is therefore called an *oblique sphere.*

An observer, travelling directly northward or southward from the equator, will see the celestial pole towards which he advances, rise gradually from the horizon, and become more and more elevated the further he proceeds. At the distance of 10 degrees from the equator, it will appear 10 degrees above the horizon; at the distance of 20 degrees, it will be elevated 20 degrees; and at the pole of the earth, or at the distance of 90 degrees from the equator, the celestial pole will appear exactly in the zenith. Hence the general rule, that *the elevation of the pole is always equal to the latitude of the observer.*

From this also it necessarily follows, that *the elevation of the equator is equal to the complement of the latitude*, or to what the latitude wants of 90 degrees; for at the equator, where the latitude is nothing, the equator passes through the zenith, that is, its elevation is 90 degrees; in latitude 10, the pole being elevated 10 degrees, the equator will be removed so much from the zenith, that is, its elevation will be 80 degrees, which is the complement of 10. So in latitude 20, its elevation will be 70 degrees; in latitude 30, it will be 60, and so on.

These truths point out an obvious and easy method of ascertaining by celestial observations the latitude of any place upon the earth. Where great accuracy

is not required, it will be sufficient to observe the elevation of the pole star, which, being situated nearly upon the pole, shows at once its elevation, and therefore the latitude of the place where the observation is made. But for greater accuracy select a star somewhat farther from the pole, but which never sets; observe its greatest altitude and its least altitude; take half the difference between these, add it to the least altitude, and the sum will be the elevation of the pole, and therefore the latitude.

To find the longitude of a place, all that is wanted is some method of ascertaining the difference in the reckoning of time between the place whose longitude is sought, and the place through which the first meridian passes; for it has been already observed, that the sun appears to move round the earth at the rate of 15 degrees per hour; so that when it is noon at any given place, it is an hour past noon to places 15 degrees eastward, and an hour before noon to places 15 degrees westward. To ascertain this difference of time, watches of superior construction and great accuracy, called Chronometers, are employed, which, being set to the time of any given place, afford the means of comparing that time with the reckoning of other places, and thus of calculating their longitude. Thus, if a navigator at sea finds, by observations upon the sun, that it is noon in the place where he is situated, when his chronometer informs him that it is two o'clock at Greenwich, he knows that his longitude is 30 degrees westward of the meridian of Greenwich.

Various other methods are employed for ascertaining both latitude and longitude; but these are all for which the learner is as yet prepared, and they will suffice to explain the principle of each operation.

The foregoing observations will enable the learner to perform, without further direction or assistance, the following Problems upon the Globes:

ON THE TERRESTRIAL GLOBE.

PROBLEM I.

To find the latitude and longitude of any given place.

PROBLEM II.

The latitude and longitude of any place being given, to find the place.

PROBLEM III.

Any place being given, to find all those places which have the same latitude or the same longitude.

PROBLEM IV.

To find the difference of latitude or longitude between any two places.

PROBLEM V.

To find the difference of time in different places.

ON THE CELESTIAL GLOBE.

PROBLEM VI.

To rectify the Globe for the latitude of any place, that is, to show that aspect of the heavens which is there exhibited. (See p. 33.)

PROBLEM VII.

To represent the three spheres.

PROBLEM VIII.

To find the meridian altitude of any fixed star in a given latitude, and in what points of the horizon it rises and sets, or whether it sets at all.

CHAPTER VII.

FURTHER DESCRIPTION OF CELESTIAL APPEARANCES.

HAVING already considered the more obvious appearances and motions of the heavenly bodies, and shown how they may be explained by the spherical figure and diurnal motion of the earth, we may proceed to remark some other appearances of a more complicated nature, which have not yet been noticed.

We cannot long direct our attention to the heavens without perceiving, that, besides the diurnal motion common to all the heavenly bodies, some of them have motions peculiar to themselves, and in a direction contrary to the former. This different motion is most observable in the Moon, which, besides partaking of the general diurnal motion of the whole heavens from east to west, will be found every successive night to have shifted her place relatively to the fixed stars about 13 degrees towards the east, so that in the period of about 27 days she makes the complete tour of the

heavens. By longer observation it is found that the Sun also performs a similar revolution, though at a much slower rate. For if on any evening we notice some fixed star near the western horizon after sunset, and observe it at the same hour for several successive evenings, we shall find it every evening nearer to the horizon, till at last it will set so soon after the sun as to be no longer visible. If then we fix upon another star farther eastwards, we shall observe the same appearances repeated, the star being nearer and nearer to the horizon at every successive sunset, till it is lost from view in the splendour of the approaching sun. If, some weeks afterwards, we observe the heavens in the east before sunrise, we shall find the same stars which the sun's approach had hidden from us, again emerging from his splendour, appearing westwards of him instead of eastwards, and rising before him instead of setting after him. Hence it appears, that the sun advances among the fixed stars from the west towards the east, successively excluding from our view different portions of the starry concave, till in about 365 days he is found to have completed the circuit of the sphere, and to have returned to the place where he was first observed. But there is something further in this motion of the sun, which cannot fail to be remarked. It evidently is not performed in a line parallel to the equator, or to the diurnal circuits of the stars; for if it were, the sun, like the stars, would always rise and set in the same points of the horizon, and always have the same meridian altitude; whereas it

is familiar to every one that he ascends far higher in our hemisphere in summer than in winter, and rises and sets in different points of the horizon at different periods of the year. On the 21st March he is known to be upon the equator, because he rises exactly in the east, and sets exactly in the west, making the day and night of equal length all over the world; from which circumstance this period is called the *Vernal* or *Spring Equinox*, (from *æquus*, equal, and *nox*, night.) From that day he continues to advance farther and farther northward, or increases more and more in north *Declination*, making the days longer and the nights shorter in the northern hemisphere, till the 21st June, the longest day, when he begins slowly to return towards the equator. This period is called the *Summer Solstice*, (from *sol*, the sun, and *sto*, to stand,) because for several days before and after the 21st June, his declination does not perceptibly vary one way or the other. On the 23rd September he is known to be upon the equator again, because he again rises in the east and sets in the west, and makes the day and night of equal length throughout the world. This is called the *Autumnal Equinox*. He then begins to have south declination, and continues to decline farther and farther southward, making the days shorter and the nights longer, till the 21st December, the shortest day, which is called, for a like reason as before, the *Winter Solstice*. From that day he begins to return northward, and reaches the equator again on the 21st March. These facts, which are so obvious as to force

themselves upon the attention of mankind, would naturally excite the wish and endeavour to ascertain the exact line of the sun's annual course among the stars. This, we may presume, was one of the earliest problems which engaged the attention and exercised the ingenuity of astronomers; and familiar as the subject is to astronomers of the present day, a little reflection will convince us, that the discovery could not have been originally made without long and careful observation. Were the stars visible at the same time with the sun, it would be easy to mark his course among them. But as he entirely effaces them from our view by his superior brightness, his course could only be ascertained in an indirect way. Having no records of this discovery, we cannot positively state by what steps it was accomplished; but a probable conjecture may be formed upon the subject. The first step would probably be to ascertain the obliquity of the sun's path, which would easily be done by merely observing how far he advances north of the equator in summer, and how far south of it in winter. These limits being found to be about 23½ degrees on each side of the equator, it was thus determined that the sun's path is a great circle of the sphere intersecting the equator in two opposite points, and inclined to it at an angle of 23½ degrees. Still the most difficult point remained, which was to place this circle in its true position on the celestial sphere. This could only be accomplished by a series of careful observations, aided probably by an artificial sphere or celestial globe, having the

equator traced upon it, and the principal stars and constellations laid down in their true relative situations. Furnished with such an instrument, and with some contrivance for measuring time in the absence of the sun, an early astronomer might observe, at the time of either equinox, that point of the equator which comes to the meridian at midnight, which, being opposite the sun's place at that time, would show him where the sun was six months before, and where it would be six months afterwards. The points where the sun's path intersects the equator being thus ascertained, and the obliquity being known by the means before mentioned, he might trace this line with tolerable accuracy on his artificial sphere, and afterwards render it more and more correct by a series of similar observations; for it is obvious that the same observation may be made at any period of the year besides the equinox, if care be taken to make allowance for the sun's declination. When the sun's actual place is 10 degrees south of the equator, the opposite point of the sphere will be 10 degrees north, and vice versâ.

This great circle described by the sun in his apparent annual course, is called the *Ecliptic*. It is divided into 12 signs, which are named after the several constellations through which it passes. The names of the signs, with their symbols, and the days on which the sun enters them, are as follows:

NORTHERN SIGNS.

Aries, or the Ram, ♈ March 21.
Taurus, the Bull, ♉ April 19.

Gemini, the Twins, ♊ May 20.
Cancer, the Crab, ♋ June 21.
Leo, the Lion, ♌ July 22.
Virgo, the Virgin, ♍ August 22.

SOUTHERN SIGNS.

Libra, the Balance, ♎ September 23.
Scorpio, the Scorpion, ♏ October 23.
Sagittarius, the Archer, ♐ November 22.
Capricornus, the Goat, ♑ December 21.
Aquarius, the Water Bearer, ♒ January 20.
Pisces, the Fishes, ♓ February 19.

The spring and autumnal signs are called *ascending* signs, because in them the sun's declination is increasing; the summer and winter signs are called *descending* signs, because in them his declination is decreasing. Each sign is subdivided into 30 degrees, and the sun makes his apparent annual progress through the ecliptic at the rate of nearly a degree in a day.

The two circles which contain the ecliptic, being drawn parallel to the equator, at the distance of the sun's extreme declination on either side, are called the *Tropics*, from a Greek word signifying *to turn*, because the sun, when he arrives at either of these circles, turns back towards the equator. The *Tropic of Cancer* is the northern limit of the sun's course; the *Tropic of Capricorn* the southern limit.

Besides the sun and moon, there are some other heavenly bodies, which, while they partake of the diurnal revolution of the whole celestial sphere, have

motions upon that sphere peculiar to themselves. The stars, properly so called, maintain invariably the same relative position, and hence are denominated *fixed stars*. But a few bodies, which at first appear to differ from the rest of the stars only by their superior brightness, are found, by longer observation, to change their places among the fixed stars, moving sometimes towards the east, sometimes towards the west, and sometimes for several nights together appearing stationary. Their ordinary and longest motion is eastward, and this accordingly is called the *direct* motion. But after having advanced for some time in this direction, they become apparently *stationary*; then move a short distance westward, when they are said to be *retrograde*; then again become stationary, till they again resume their eastward progress, which being always continued longer and farther than their westward or retrograde motion, causes them to perform at length, though in this interrupted manner, the complete circuit of the sphere. These bodies, from the irregularity of their motions, are not unaptly termed *Planets*, or *Wandering Stars*.* Five of them, namely, Mercury, Venus, Mars, Jupiter, and Saturn, are easily discernible by the naked eye, and have been known from time immemorial. To this number modern astronomers have added others, which will be named and particularized hereafter. Here it only remains to be remarked, that the wanderings of the five just mentioned are confined within

* From the Greek word πλανητης, a *wanderer*.

the limits of eight degrees on each side of the ecliptic. Hence that broad belt called the *Zodiac,* which accompanies the ecliptic, and which was naturally distinguished from the rest of the celestial sphere as the region of the planetary motions. The signs of the ecliptic are also called signs of the Zodiac, and the word Zodiac, being derived from a Greek word signifying animal, is supposed to bear reference to the figures of animals of which those signs chiefly consist.

Having thus considered the apparent peculiar motions of the sun, moon, and planets, our attention must now be directed to the explanation of these appearances.

CHAPTER VIII.

ANCIENT AND MODERN EXPLANATION OF THE FOREGOING APPEARANCES.

As the diurnal revolution of the heavens was long considered to be a real and not an apparent motion, it is not to be wondered at, that these additional and peculiar motions of the sun, moon, and planets were regarded by the ancients in the same light. As they not unnaturally conceived the stars to be attached to the concave surface of a solid sphere or firmament, by the revolution of which they were all simultaneously

carried round the earth in 24 hours, they were led by analogy to account for the motions of the other heavenly bodies in the same way. But as they could not suppose the sun, moon, and planets to be attached to the same sphere with the fixed stars, with respect to which they were constantly changing their place, they assigned to each of them a sphere of its own, that is, they supposed each of them to be attached to the concave side of a solid and transparent sphere, by whose revolutions they were carried, with different velocities and in different directions, round the earth, the common centre of the whole. Each of these interior spheres was supposed to revolve by a motion of its own, and at the same time to be affected by the motion of the outer sphere of the fixed stars. Thus the sun was carried round from east to west by the communicated movement of this outer sphere, which produced his diurnal revolutions and the vicissitudes of day and night; but at the same time the sphere in which he was fixed, had a relative motion of its own in an eastward direction, which occasioned his annual revolution and the continual shifting of his place with regard to the fixed stars: This motion was more easy, they thought, when carried on edgeways, and not in direct opposition to the motion of the outer sphere; and hence the inclination of the axis of the solar sphere to that of the fixed stars, and consequently the obliquity of the ecliptic and the changes of the seasons. The moon being placed below the sphere of the sun, had both a shorter course to finish, and was less

obstructed by the contrary movement of the sphere of the fixed stars, from which she was farther removed. She finished her period, therefore, in a shorter time, and required but a month, instead of a year, to complete it. In the same manner, the five planets were supposed to be attached to their respective transparent spheres placed one within another, the situation and order of the whole being as follows: first, the sphere of the Moon; beyond that, but within the sphere of the Sun, were placed those of Mercury and Venus; and beyond the sphere of the Sun, those of Mars, Jupiter, and Saturn; the whole being inclosed by the great sphere of the fixed stars, and by certain crystalline spheres or heavens, which were supposed to be placed beyond the visible firmament.* Such was the fanciful notion which was formed of the structure of the universe by the ancient astronomers of the Italian school, and which, after receiving successive improvements and additions from Aristotle, Eudoxus, Callippus, Apollonius, and Hipparchus, became established under the name of Ptolemy, and prevailed for ages in all the schools of science. To this notion of the spheres Pythagoras added a peculiar fancy of his own, which, as it is occasionally alluded to in the writings of the poets, deserves some share of notice. He "conceived that the celestial spheres in which the

* See Smith's Philosophical Essays, History of Astronomy, Sect. IV. from which the foregoing account of the ancient system of the spheres is borrowed, partly in the same words.

planets move, striking upon the ether through which they pass, must produce a sound, and that this sound must vary according to the diversity of their magnitude, velocity, and relative distance. Taking it for granted that every thing respecting the heavenly bodies is adjusted with perfect regularity, he further imagined, that all the circumstances necessary to render the sounds produced by this motion harmonious, were fixed in such exact proportions, that the most perfect harmony is produced by their revolutions. This fanciful doctrine respecting the music of the spheres gave rise to the names which Pythagoras applied to musical tones. The last note in the musical octave he called *Hypate*, (ὑπατη, highest,) because he supposed the sphere of Saturn, the highest planet, to give the deepest tone; and the highest note he called *Neate*, (νεατη, the lowest,) from the sphere of the moon, which being the lowest or nearest the earth, he imagined produced the shrillest sound. In like manner of the rest. It was said of Pythagoras by his followers, who hesitated at no assertion, however improbable, which might seem to exalt their master's fame, that he was the only mortal so far favoured by the gods as to be permitted to hear the celestial music of the spheres."*

* Enfield's History of Philosophy, vol. i. book ii. chap. xii.—See also that highly interesting fragment of Cicero's writings, entitled *Somnium Scipionis*, at the passage which begins with these words, "Nonne adspicis quæ in templa veneris," &c.

It would be tedious and of little use to point out all the objections to which this ancient system of Astronomy is liable, or the various expedients which were devised by Ptolemy and others for obviating these objections, and reconciling the system with all the phenomena of the heavenly bodies.* Suffice it to observe, that, though by these devices it was made to correspond pretty well with actual appearances, yet it ascribed such intricacy to the structure of the world, and was so inconsistent with the usual simplicity and beauty of nature, as not without reason to have provoked the bold remark which is said to have been uttered by Alphonso, king of Castile, that, had he been present at the creation of the world, he could have counselled the Deity to construct it better.

The only system which satisfactorily explains all the movements and appearances of the heavenly bodies, and which, from having stood the test of a long series of accurate observations, may now be considered as placed beyond dispute, is that taught by Copernicus, a German philosopher of the 16th century, and from him called the Copernican System. It is said, indeed, to have been taught long before, by Pythagoras, who flourished 500 years before the Christian era. But this is somewhat doubtful, and at all events, as Copernicus was the first to establish it on just grounds, he has the best title to the honour of the discovery.

* For an account of these expedients, see Smith's Philosophical Essays, as referred to above.

of its orbit, so that it makes with the perpendicular *pr* (see Fig. 8.) an angle of about 23½ degrees, the effect of which is, that the sun, in his apparent annual revolution, appears sometimes north and sometimes south of the equator; for the axis NS keeping constantly parallel to itself in all parts of the earth's orbit, it is evident that, when the earth is at A, the sun at C, instead of appearing directly over the equator, will appear north of it, and just as far north as the pole N is distant from the perpendicular *p*, that is, 23½ degrees; and that, on the other hand, when the earth is in the opposite part of its orbit, at B, the sun will appear the same distance south of the equator, and will only be over the equator at the two intermediate points.

This inclination of the earth's axis to the plane of its orbit affords a very simple and easy solution of the vicissitudes of the seasons, and the variations in the length of the day. For when the north pole is turned towards the sun, as at A, (Fig. 8.) the sun is vertical to those parts of the earth which are 23½ degrees north of the equator, and his light extends as far beyond the north pole; so that all places within that distance of the pole, perform their diurnal revolution without losing sight of the sun, and all other places north of the equator perform a greater part of their revolution in light than in darkness. In this situation of the earth, therefore, the inhabitants within the polar circle, which is drawn at the distance of 23½ degrees from the pole, have *no night;* and all other

inhabitants of the northern hemisphere have longer days than nights. The sun also appears to them at his greatest elevation above the horizon, and darts his rays upon them most directly. These circumstances will be reversed, when the earth is at the opposite point of its orbit, B; for then the north pole being turned from the sun, the sun will be vertical to those parts of the earth which are 23½ degrees south of the equator, and his light will consequently fall short of the north pole by an equal distance; so that all places within the polar circle will revolve wholly in darkness, and have *no day;* and every place between that circle and the equator will revolve longer in darkness than in light, and consequently have shorter days and longer nights, the sun, at the same time, appearing at his least elevation. At the two intermediate points of the earth's orbit, the sun will be vertical to the equator; the boundary of light and darkness will fall exactly upon each pole, and equally divide all the parallels of latitude in both hemispheres; so that the day and night will then be of equal length all over the world. This must happen twice in every revolution of the earth, and these are the two periods which we call the Vernal and the Autumnal Equinox. But it should be observed that at the equator the days and nights are equal throughout the year, because in every position of the earth with respect to the sun, that circle is always equally divided by the boundary of light and darkness. And the nearer any place is to the equa-

tor, the less is the disproportion between the days and nights in summer and in winter.

Thus it is that the annual revolution of the earth round the sun, with its axis constantly inclined in the same direction to the plane of its orbit, causes the apparent revolution of the sun in that oblique circle which we call the Ecliptic, and produces that vicissitude of seasons which is so grateful and salutary to the inhabitants of the earth. We have only to add on this subject, that the direction of the earth's revolution, as well as of all the other planets, is from west to east, or from right hand to left, as seen from the sun; and it is completed in 365 days, 5 hours, 48 minutes, and 49 seconds, which is the length of our year.

This explanation of the phenomena of the seasons points out to our notice certain divisions of the earth's surface which are treated of by geographers under the name of *Zones*. In consequence of the inclination of the earth's axis, the sun, as we have seen, appears sometimes north and sometimes south of the equator, the limits of his declination on either side being exactly equal to the angle which the earth's axis makes with a perpendicular to the plane of its orbit, that is, to 23½ degrees. The *Tropic of Cancer* is a circle drawn parallel to the equator, marking the extreme limit of the sun's northern declination. The *Tropic of Capricorn* is a similar circle, marking the extreme limit of the sun's southern declination. These correspond exactly to the two circles of the same name which have already been noticed on the celestial

globe. The space included between these circles is called the *Torrid Zone*, which, extending 23½ degrees on each side of the equator, has an entire breadth of 47 degrees. It is only to the inhabitants of this region that the sun can ever appear vertical, which happens to those immediately under the tropics once a year, but to those who live in any part within the tropics twice a year. As the light of the sun, when he is in the Tropic of Cancer, reaches 23½ degrees beyond the north pole, and the same distance beyond the south pole, when he is in the Tropic of Capricorn, there is an obvious reason for drawing an imaginary circle at that distance round each pole, to mark the utmost limits of those parts of the earth which may perform an entire diurnal revolution within the boundary of light or darkness. Such are the *Arctic Circle* round the north pole, and the *Antarctic* round the south pole. The regions they contain are called the *Frigid Zones*, and it is only in those parts that the sun can remain above or below the horizon for 24 hours or more. The two spaces which remain, included between the torrid and the two frigid zones, are only characterized by the negation of those circumstances which respectively distinguish the other divisions; the sun in those parts being never vertical, as in the torrid zone, and the day or night being never of 24 hours duration, as in the frigid zones. These regions are called the *Temperate Zones*, the breadth of each being 43 degrees.

CHAPTER X.

THE FOREGOING SUBJECT FURTHER ILLUSTRATED BY THE GLOBES.

THE knowledge which the learner has now acquired of the Ecliptic, will enable him to apply the Globes to their most interesting and important uses. A circle bearing this name will be found traced upon both the terrestrial and the celestial globe; but, as was observed respecting the horizon,* it belongs more properly to the latter than the former; at least it is best understood on the latter, because there it is a fixed circle, placed in that situation which nature assigns it, and justly representing the sun's apparent path among the stars; whereas on the terrestrial globe, its position varies according to the place of the first meridian, and represents the sun's path no otherwise than as it serves to show in what parellel of latitude he is performing at any given time his diurnal circuit. The same purpose, however, is equally well answered by that scale called the *Analemma*, which, extending from tropic to tropic, contains the names of the months, with their divisions into days, so placed as to correspond with the sun's successive points of declination. The sun's true path over the surface of the earth is a spiral line

* See p. 29.

winding round the torrid zone as many times as there are days in the year, and making its circuits closer and closer the nearer it approaches to either tropic. But the sun's path in the heavens is exactly such a circle as we find drawn upon the celestial globe. It is therefore better, in order to obviate misapprehension, to employ this globe alone in all such problems as relate to the ecliptic, or if the terrestrial globe be employed in the same way, let it be distinctly understood that it is then converted, so far as may be, into a celestial globe.

I.—*PROBLEMS TO BE PERFORMED ON THE CELESTIAL GLOBE.*

PROBLEM I.

To find the Sun's Place in the Ecliptic, otherwise called its Longitude.

For this purpose the wooden circle which surrounds the globe, representing the rational horizon, exhibits a table consisting of two broad circles or belts, each divided into twelve parts, the outermost containing the names of the months, with their subdivisions into days, and the inner one the names of the twelve signs of the zodiac, with their subdivisions into degrees. These divisions are so arranged, that, by finding the day of the month on the outer circle, you find the sun's place on that day in the corresponding point of the inner circle. When greater accuracy, however,

is required, it is better to consult an *Ephemeris*,* or Astronomical Almanack, in which the sun's longitude, found by calculation, is given to a second for every day in the year. The corresponding place may then be found on the ecliptic of the celestial globe, and a small patch or mark fixed there to represent the sun, will be found convenient in the ensuing problems.

Here let it be carefully remarked, that the term *Longitude* is employed in a different sense from that in which it has been already explained. On the *celestial* globe it signifies, not distance from the first meridian reckoned on the equator, but distance from the equinoctial point reckoned on the *ecliptic*; and it is usually stated by means of the signs and their subdivisions. Thus the sun's longitude on the 1st of January, 1828, was 10° 7′ 5″ in Capricorn. A similar difference must be observed in the application of the term *Latitude*, which also on the *celestial* globe refers to the *ecliptic*, and is applied to the stars and planets to denote their distance from that circle northward or southward. To the sun, of course, it is not applicable, because, being always in the ecliptic, it can have no latitude.

* *White's Ephemeris* is the one commonly employed, a book indispensable to every student of astronomy.

PROBLEM II.

To find the Sun's Declination, or Distance from the Equator.

The sun's place in the ecliptic, as found above, being brought to the brazen meridian, its declination, or distance from the equator, may be observed by means of the graduated scale thereon contained.

PROBLEM III.

To find the Sun's Right Ascension.

By the *right ascension* of any heavenly body is meant its distance from the equinoctial point reckoned on the equator. The sun's place being brought to the brazen meridian, as in the preceding problem, that point of the equator which the meridian crosses is his right ascension.

PROBLEM IV.

To find the Sun's Meridian Altitude, and the Time of Sunrise and Sunset, at any given time, in any given place.

If the latitude of the given place be unknown, find it on the terrestrial globe, and then rectify the celestial globe for that latitude, according to the principles laid down in Chapter VI. p. 33. Find the sun's place for the given day, as above, and bring it to the meridian: the globe then represents the position of the heavens on the noon of that day; and the distance of the sun from the horizon, or its meridian altitude, may

be observed by means of the brass meridian. The globe being in this situation, set the hour index to twelve; and then, if the sun's place be moved first to the eastern, and next to the western side of the horizon, the index will show the time of sunrise and sunset.* The same operation enables us to ascertain the sun's *amplitude*, or the distance at which he rises from the east and sets from the west point, either towards the north or towards the south. It shows us, in short, the whole extent and position of the sun's *diurnal arc* at the given time and place. By this problem, also, the length of the longest and shortest day may be found, by taking the first of Cancer as the sun's place in the one case, and the first of Capricorn in the other.

If the given place be within the polar circle, the pole being elevated according to the latitude, it will be seen on turning the globe, that there is a certain portion of the ecliptic near the upper tropic which does not descend below the horizon, and an equal portion near the lower tropic which never mounts above it. By observing the extent of those portions, and then referring to the table of the sun's longitude on the wooden horizon, it may easily be ascertained during what period of the year the sun ceases to rise or set in that latitude.

* Instead of the hour index, the equator may be used for the same purpose, by observing how much of it has passed the meridian when the sun's place is moved to the horizon, and allowing an hour for every fifteen degrees, or four minutes for every degree. This, in fact, is the better method, because it admits of greater accuracy.

PROBLEM V.

To find the Situation of the Heavens at any given hour.

The solution of this problem will be easily seen from the preceding; for the globe being prepared in the same way, and turned from east to west in imitation of the diurnal motion of the heavens, its motion may be arrested at any hour to which the index points, and then the position of the globe will represent the position of the heavens at that hour, showing what stars or constellations are then above the horizon, and how they are situated with respect to it. If the given hour be in the day time, we may ascertain by this problem how far the sun is distant from the meridian, that is, his *azimuth*, and also his altitude. If it be in the night time, we may ascertain how far he is depressed below the horizon, and when twilight (which requires that the sun should be within 18 degrees of the horizon) begins and ends. And if the globe, thus rectified according to the hour of the night, be carried out of doors, and placed with its meridian due north and south, the stars and constellations marked upon its surface will stand exactly under those which they represent in the real heavens; thus furnishing to the student an easy means of learning the names and situation of the stars.

The problems which follow are to be performed solely on the terrestrial globe, the sun being supposed to be immediately above the globe, and the wooden circle being used to represent the *boundary of illumination.*

II.—*PROBLEMS ON THE TERRESTRIAL GLOBE.*

PROBLEM VI.

To represent the Situation of the Earth with respect to the Sun at the Summer Solstice, at the Winter Solstice, at the Equinoxes, or at any intermediate time.

For the summer solstice, raise the north pole 23½ degrees above the wooden circle, and conceive the sun to be shining at a distance immediately above the globe. The wooden circle will then represent the limit of the sun's light, all above it being illumined, and all below it being in darkness. In this situation it will be seen that the sun is vertical to those parts of the earth which lie under the tropic of Cancer, and that, consequently, his light extends 23½ degrees beyond the north pole, and falls short of the south pole by the same distance. The globe being turned from west to east, in imitation of the earth's real motion, it will be observed that all places within the *arctic* circle perform the whole of their revolution in light, while all places within the *antarctic* circle revolve wholly in darkness, thus illustrating the sun's continued presence in summer, and his continued absence in winter, in the polar regions. It will also be observed that all places in the northern hemisphere, not within the polar circles, perform a greater part of their revolution in light than in darkness, and that the reverse of this is the case in the southern hemisphere, while the equator is equally divided by the boundary of illumination; and the

nearer any place is to the equator, the less, it will be perceived, is the difference between its diurnal and its nocturnal arc—all which is beautifully illustrative of the different proportions of day and night in summer and in winter in different latitudes. If it is wished to ascertain the proportion between day and night at this season of the year at any place, all that is necessary to be done for this purpose is to observe how much of a parallel of latitude passing through the place lies above, and how much below, the boundary of illumination, allowing an hour for every 15 degrees. Or if the place be brought to the meridian, and the hour index set to 12, the place being moved to the wooden circle on either side, the number of hours traversed by the index will show half the length of the day, from which the whole length both of the day and the night may be easily ascertained. The sun's meridian altitude at the summer solstice may also be found for any place, by bringing that place to the brass meridian, and observing how far it is distant from the boundary of illumination, for that distance is always equal to the sun's altitude.

To represent the earth's situation with respect to the sun at the *winter solstice*, the *south* pole of the globe must be raised 23½ degrees above the wooden circle, and to represent its situation at the *equinoxes*, each pole must be made to coincide with this circle.*

* In thus shifting the position of the globe with respect to the wooden circle, it may be well to caution the learner against sup-

After what has been said in the case of the summer solstice, it is needless to detail the several similar observations which may be made in these two cases.

In like manner the earth's situation with respect to the sun may be shown for any intermediate time, by elevating the pole above the boundary of illumination according to the sun's declination, the north pole for north declination, the south pole for south. This being done, the learner will be prepared for the interesting problem which follows.

PROBLEM VII.

To show at one view all the Places to which the Sun is rising, setting, or culminating, and where it is vertical, at any given moment.

Having found the sun's declination on the given day, and elevated the north or south pole accordingly, bring the place where you are situated to the brazen meridian, and set the hour index to 12. Then, if the given hour be *before noon*, turn the globe *westward*; if it be *afternoon*, turn it *eastward*, till the index has traversed over as many hours, or parts of an hour, as

posing that the earth moves in a similar way. Let it be carefully remembered that the earth's axis, instead of moving as the axis of the globe is moved in this problem, continues always parallel to itself, or pointed in the same direction; and that which really moves is the *boundary of light and darkness*. But as the wooden circle which represents this boundary is not made moveable, its change of place can only be represented by moving the globe within it.

intervene between noon and the given time of day. This being done, the position of the globe with respect to the wooden circle, exactly represents the position of the earth at that time with respect to the boundary between light and darkness. To all places above the wooden circle, it is day; to all places below, it is night. To those places over which this circle passes on the western side, the sun is rising; to those over which it passes on the eastern side, the sun is setting. To those under the upper half of the brazen meridian, it is mid-day; to those under the lower half, it is midnight; and that particular place under the upper half of the meridian, the latitude of which corresponds with the sun's declination, is the point where the sun is then vertical. That place, it will be observed, is exactly at the summit of the globe, as the sun is there at the summit of the heavenly concave; and every other place in the illuminated hemisphere has, in like manner, the altitude of the sun equal to the distance of the place from the wooden circle which represents the boundary of light and darkness. The depression, also, of any place below this circle, is an exact measure of the sun's depression there below the horizon; and thus the extent of twilight may be ascertained by observing what places are immerged within the bounds of darkness less than 18 degrees. This comprehensive problem is perhaps the most interesting and instructive of all the uses to which the globe may be applied.

CHAPTER XI.

OF THE ELLIPTICAL FORM OF THE EARTH'S ORBIT, AND THE LAW OF THE EARTH'S MOTIONS.

THE seasons are not of exactly equal length; for from the vernal equinox, which falls on the 21st of March, to the autumnal equinox, which falls on the 23rd September, there are 186 days; whereas between the autumnal and the vernal equinox, there are only 179; so that the summer part of the year exceeds the winter part by about seven days. This is owing to a circumstance, for the discovery of which we are indebted to Kepler, a German philosopher, who flourished at the commencement of the 17th century; which is, that the earth's orbit is not a circle, but an ellipse, having the sun in one of its foci. Let ABCD (Fig. 9.) represent the earth's elliptical orbit, S the sun in one of its foci, and EFGH the ecliptic, or plane of the earth's orbit extended to the fixed stars: While the earth moves in its orbit from B through C to D, the sun appears to move in the ecliptic from F through G to H, passing through the six northern signs; and while the earth proceeds from D through A to B, the sun appears to move from H through E to F, through the six southern signs. Now the line HF bisects the circle EFGH, but divides the ellipse ABCD unequally; so that while the sun appears to

pass through the northern signs, the earth moves through more than half its orbit; but describes less than half its orbit during the sun's passage through the southern signs. The sun, therefore, must appear to be longer in passing through the six northern, than through the six southern signs, even if the earth moved in its orbit with uniform velocity. But the fact is, that the earth moves slower in the summer part of its orbit than in the winter part, because its distance from the sun is greater. For a double reason, therefore, the sun's apparent motion is slower in the northern signs than in the southern. The difference is found by observation to be 7 days and 17 hours.

Hence it further appears that the earth is nearer to the sun in winter than in summer. The distance of the sun, S, from K, the centre of the earth's elliptical orbit, which is called the *eccentricity* of the earth's orbit, is 1,597,000 miles. The earth will, therefore, be 3,194,000 miles nearer the sun at the point A, which is its situation in winter, than at the point C, its situation in summer. This is confirmed by observations upon the sun's disk, the diameter of which in winter is 32′ 38″, in summer 31′ 32″. But here the question will naturally arise, "Why have we the coldest weather when the earth is nearest the sun?" In answer to which, it may be observed, that the eccentricity of the earth's orbit bears no greater proportion to the earth's mean distance from the sun, than about 1 to 60, and therefore can occasion but little variation in the heat and cold of different seasons. So incon-

siderable, in fact, is the influence of this cause, that it is completely counteracted by the effect which arises from the inclination of the earth's axis. In winter the northern pole being turned from the sun, its rays then fall so obliquely upon us, as not to impart the full benefit of their heat; and its visits, moreover, are so short, that the effect of his presence is counteracted by that of his longer absence. In summer, on the contrary, the sun's rays fall more directly upon us, and therefore in greater quantity and with greater power; and as the days are then long, and the nights short, the earth and air are heated in the day-time more than they are cooled in the night, so that the heat continually accumulates.

Though the motion of the earth in its orbit is not uniform, being, as we have said, slower in summer than in winter, yet it is regulated by a certain law, which is, that a line drawn from the centre of the sun to the centre of the earth describes equal areas in equal times. Thus, if AE (Fig. 10.) represent the earth's elliptical orbit, and lines be drawn from S, the sun's place or focus, to the points B, C, D, E, F, &c. so as to make the spaces ASB, BSC, CSD, DSE, ESF, &c. equal to one another, then the portions of the orbit intercepted by these lines, namely, AB, BC, CD, DE, EF, &c. though unequal in length, will be described by the earth in equal times. This remarkable law holds with respect to all the planets, and is one of the laws known by the name of Kepler's laws, from their discoverer.

The following terms and particulars relating to the earth's orbit should here be carefully impressed on the mind.

1. The point of the earth's nearest approach to the sun, is called its *Perihelion* or *Higher Apsis.*

2. The point of its greatest distance is called its *Aphelion* or *Lower Apsis.*

3. The longer diameter of the ellipse which joins these two points, is called the line of the Apsides.

4. The place of the earth's aphelion is the 9th degree of Capricorn.

5. The eccentricity of the earth's orbit is the distance of the sun from the central point, which is estimated at 1,597,000 miles.

6. The distance from the sun to the extremity of the shorter diameter of the earth's orbit, (LS, Fig. 9.) is the earth's mean distance from the sun, estimated at 95,000,000 miles. How this is ascertained will be shown in a subsequent chapter.

CHAPTER XII.

OF THE SOLAR AND SIDEREAL DAY, AND THE EQUATION OF TIME.

THE succession of day and night is caused, as we have seen, by the rotation of the earth upon its axis. But by reason of the earth's motion in its orbit round the sun, a day is somewhat longer than the time which the earth takes to perform one complete revolution upon its axis. For, as the earth's motion in its orbit causes the sun to appear every day a little further eastward in the ecliptic, it will require something more than one complete rotation to bring round the same meridian from the sun to the sun again. Between the noon of one day and the noon of the next, the earth must perform one complete rotation, and just so much of another as is equivalent to the sun's daily advance eastward. The interval between one noon and the next is called a *Solar day*, the mean or average length of which is 24 hours. But the earth's rotation upon its axis is completed in 23*h*. 56′ 4″. This is called a *Sidereal day*, because it is measured by means of the fixed stars; for the stars are situated at such an immense distance from us, that the diameter of the earth's orbit is but a point in comparison, and therefore any meridian will revolve from a fixed star to that star again, in exactly the same time as if the

earth stood still in its orbit, and had only a diurnal motion upon its axis. The sidereal day is, therefore, shorter than the solar day by 3′ 56″; and this gain of time, by the stars, amounts in the course of the year to one entire day; so that the year of 365 solar days includes 366 sidereal days, or, which is the same thing, 366 rotations of the earth upon its axis.

We have said that the length of the solar day is 24 hours. This, however, must be understood of the *average* or *mean* length; for the intervals between noon and noon vary in length, being sometimes a little more, sometimes a little less, than 24 hours. In order to understand the reason of this, it is necessary to recur to the distinction which has just been pointed out, between the solar and the sidereal day. The excess of the solar above the sidereal day has been shown to arise from the advance which the earth has made in its orbit, and the consequent apparent advance of the sun eastward in the ecliptic during the earth's rotation. Were this daily advance of the sun towards the east always uniform in its amount, the solar days would all be of the same length. But as this apparent motion of the sun is owing to the real motion of the earth in its orbit, it must of course be subject to the same inequality. It is, accordingly, faster in winter, when the earth is in that part of its orbit which is nearest the sun; and slower in summer, when the earth is more remote from the sun. Now it is evident, that the further the sun advances eastward, while the earth performs its rotation upon its axis, the more will the

interval between noon and noon be *protracted.* Whereas, when it advances a shorter distance than usual in its eastward course, it will come to the meridian sooner, and thus *shorten* the solar day.

This, however, is not the only cause of the difference in the length of the solar days. For were the earth's motion in its orbit, and the consequent apparent motion of the sun in the ecliptic, always uniform, still a difference in the length of the solar days would arise from the *obliquity* of the sun's apparent path in the heavens. This can only be illustrated by means of a globe. Let equal portions be taken on the ecliptic and the equator of a celestial globe, by placing marks at every tenth degree, and then, the globe being turned westward, it will be found that every successive mark upon the ecliptic, between the first of Aries and the first of Cancer, will come *sooner* to the meridian than the corresponding mark upon the equator, the difference increasing from the first of Aries to the 15th of Taurus, and diminishing from that point to the first of Cancer, where the two corresponding marks come to the meridian together. But between the first of Cancer and the first of Libra, the successive marks upon the ecliptic will come to the meridian *later* than the corresponding marks upon the equator, the difference increasing to the 15th of Leo, and decreasing from that point till the marks again coincide at the first of Libra. The same will be found in the southern portion of the ecliptic. Thus it appears, that though the sun should move uniformly in the ecliptic, yet equal

portions of his progress in that circle do not make equal differences in his situation as referred to the equator; and it is only by referring his place to the equator, or by finding what is called his *right ascension*,* that we can determine with accuracy the amount of his daily removal eastward, and consequently the amount of that additional time by which the solar exceeds the sidereal day. While passing through the signs Pisces and Aries, where his path is most inclined to the equator, his daily advances in right ascension being smallest, he will come proportionably sooner to the meridian, and consequently render the solar day *shorter* than the mean. But while passing through Gemini and Cancer, where his path lies nearly parallel to the equator, and crosses the meridians after they have in some degree converged, his daily advances in right ascension being the greatest, he will come accordingly later to the meridian, and render the solar day *longer* than the mean.

There are, then, two causes which combine to render the solar days of unequal length; first, the varying velocity of the sun's apparent motion in the ecliptic, occasioned by the earth's unequal motion in its orbit; and next, the obliquity of the ecliptic to the equator. Hence arises the distinction between *mean time* and *apparent time:* the former being that measurement of time which is made by a well regulated clock or watch, and which reckons the duration of the day uniformly at 24 hours; the latter being the time shown by the

* See above, p. 57.

dial, which, on account of the unequal length of the solar days, is sometimes faster, sometimes slower than the clock. The difference between mean and apparent time is called the *equation of time*. According to the first of those two causes which occasion the difference between mean and apparent time, namely, the unequal velocity of the earth's motion in its orbit, the clock and sun would agree only twice in the year, when the earth is in its perihelion, that is, at the end of December; and again, when the earth is in its aphelion, or near the end of June; the sun being faster than the clock between the aphelion and perihelion, but slower between the perihelion and aphelion. According to the other cause, if that operated alone, the sun and clock would agree four times in the year, namely, at the two equinoxes, and the two solstices, the sun being faster than the clock while passing through the two quarters of ascending signs, but slower while passing through the two quarters of descending signs. The two causes sometimes concur with, sometimes counteract, one another; and it is from the combined calculation of each that equation tables are constructed. The following concise table, adapted to the second year after leap year, will always be found within about a minute of the truth, and therefore sufficiently accurate for all common purposes. The difference, it will be observed, between mean and apparent time is never greater than 16 minutes, and the days on which the clock and sun agree, are April 15, June 16, August 31, and December 23.

A TABLE SHOWING THE EQUATION OF TIME.

Clock faster than the Sun.	min.	Clock slower than the Sun.	min.	Clock faster than the Sun.	min.	Clock slower than the Sun.	min.
Dec. 26.	1	Apr. 19.	1	June 20.	1	Sep. 3.	1
28.	2	24.	2	25.	2	6.	2
30.	3	30.	3	29.	3	9.	3
Jan. 1.	4	May 13.	4	July 5.	4	12.	4
3.	5	29.	3	11.	5	15.	5
5.	6	June 5.	2	28.	6	18.	6
7.	7	10.	1	Aug. 9.	5	21.	7
9.	8	15.	0	15.	4	24.	8
12.	9	..	..	20.	3	27.	9
15.	10	..	..	24.	2	30.	10
18.	11	..	..	28	1	Oct. 3.	11
21.	12	..	..	31.	0	6.	12
25.	13	..	..	..	..	10.	13
31.	14	..	..	..	..	14.	14
Feb. 10.	15	..	..	..	..	19.	15
21.	14	..	..	..	..	27.	16
27.	13	..	..	..	..	Nov. 15.	15
Mar. 4.	12	..	..	..	..	20.	14
8.	11	..	..	..	..	24.	13
12.	10	..	..	..	..	27.	12
15.	9	..	..	..	..	30.	11
19.	8	..	..	..	..	Dec. 2.	10
22.	7	..	..	..	..	5.	9
25.	6	..	..	..	..	7.	8
28.	5	..	..	..	..	9.	7
April 1.	4	..	..	..	..	11.	6
4.	3	..	..	..	..	13.	5
7.	2	..	..	..	..	16.	4
11.	1	..	..	..	..	18.	3
15.	0	..	..	..	..	20.	2
..	..	..	..	..	..	22.	1
..	..	..	..	..	..	24.	0

CHAPTER XIII.

OF THE CALENDAR.

We have seen that the year contains not any exact number of days, but so many days and a certain fraction of a day, (namely, 365*d.* 5*h.* 48′ 49″.) This circumstance occasioned for a long time great perplexity in the computation of the year, and the adjustment of the calendar. The Egyptians, according to Herodotus, were the first who fixed the length of the year, making it to consist of 360 days, which they distributed into 12 months of 30 days each. This computation, by omitting more than five days, would obviously occasion great confusion, and at a very early period it was found, (and the Egyptians claim the merit of the discovery, which they attribute to Hermes or Thoth,) that the duration of the year must be reckoned at 365 days. This, however, still fell short of the true year by almost six hours, so that four Egyptian years would be less than four natural years by almost one whole day. By this omission of one day in four years, the commencement of the civil year would gradually fall back in the natural year, and shift in the course of time through all the seasons. To remedy this great inconvenience, it was enacted by the authority of Julius Cæsar, that one additional day should be introduced into the calendar every

fourth year, which is called *Bissextile* or *Leap Year.* This additional day is now placed at the end of the month of February, which has, therefore, every fourth year, 29 days instead of 28. But in the ancient Roman calendar, the 6th of the calends of March, corresponding to the 23rd of February, was that year reckoned twice over; hence the year was called *bissextilis.* The term *leap year* is derived from the circumstance of its causing the numbers of the days of the month to fall a day later in the week than they otherwise would. For as the ordinary year of 365 days contains 52 weeks and one day more, the number of the month, instead of remaining fixed to the same day of the week, shifts ordinarily to the following day; but when a leap year occurs, which contains two additional days, the number of the month is removed *two days* onward in the week. Thus, if the 1st of March in one year fall on Monday, it will fall the next year on Tuesday; but if it be a leap year, it will leap or pass over Tuesday, and fall on Wednesday.

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ginning of the year fixed always to the same season, Pope Gregory XIII. in 1582, undertook a further reformation of the calendar. Finding that the error at that time amounted to about 10 days,* which the Julian reckoning had counted too much, he ordered that 10 days should be struck out of the calendar, by calling the 5th of October in that year the 15th. And to prevent all variation for the future, it was ordained that every hundredth year, which according to the Julian arrangement should have been a leap year, should be a common year, with the exception, however, that with respect to every four hundredth year, the old arrangement should remain unaltered. This was equivalent to taking from the Julian reckoning three days in 400 years, which is nearly the same as taking out one day in 129 years. Thus the natural and the civil year are brought to so near a correspondence, that several thousand years must elapse before there will be occasion for any further correction of the calendar.

This method being introduced and established by Gregory XIII. is called the Gregorian account, or the *New Style*, as the Julian calendar is now called the *Old Style*. It was immediately adopted in all countries where the papal authority was acknowledged. But it was not admitted into this country till the year 1752; at which time it was necessary to

* Reckoning from the year 325, when the Council of Nice fixed the vernal equinox to the 21st of March.

strike 11 days, instead of 10, from the calendar, and this was done by calling the 3rd of September in that year the 14th.

CHAPTER XIV.

OF THE PRECESSION OF THE EQUINOXES AND THE SIDEREAL YEAR.

On a slight inspection of the celestial globe, it will be observed, that the signs of the ecliptic do not correspond in place with those constellations from which they take their names. This is owing to a circumstance, which yet remains to be noticed, attending the earth's annual motion round the sun. In the account given above of the phenomena of the seasons, it was stated, that the earth's axis always continues parallel to itself. This statement is sufficiently accurate for the purpose of what it was brought to explain; but the progress of our subject now requires that the statement should be somewhat modified: for the strict truth is, that, owing to the attractive power of the moon upon the redundant matter about the equator, the axis of the earth has a very slow conical motion westward, the centre being fixed, while each pole describes a circle round an imaginary line passing through the centre, perpendicular to the plane

of the earth's orbit. Thus, let NS (Fig. 11.) represent the earth's axis inclined to the perpendicular PR, at an angle of 23½ degrees, as before shown: Then, if the line NS be supposed to turn upon the centre C, round the perpendicular PR, so that the arm CN may describe the cone C*n*N, and the arm CS the opposite cone CS*s*, this will represent the slow motion which affects the earth's axis, and causes what is called the *Precession of the Equinoxes.* For the necessary effect of it is, so to alter the position of the plane of the equator, that the points of its intersection with the plane of the earth's orbit are shifted continually westward. This will be best understood by means of the following problem upon the *celestial* globe.

PROBLEM

To illustrate the Precession of the Equinoxes.

Let the broad wooden circle represent the plane of the earth's orbit, or, which is the same thing, the plane of the ecliptic. Place the axis of the globe perpendicular to the wooden circle; the ecliptic on the globe will then make with it an angle of 23½ degrees: consequently, if the wooden circle represents the ecliptic, the circle which commonly represents the ecliptic will now represent the equator, and the two points in which this circle cuts the wooden horizon, will represent the equinoctial points. If the globe, in this position, be turned slowly round from east to west, it will represent that slow motion of the earth by which its axis deviates from the self-parallel position, and the effect of which

is, as will be seen by the globe, to remove the equinoctial points in the same direction.

This motion, however, is so extremely slow, that the equinoctial points recede only 50¼ seconds every year, or one degree in about 72 years. It will consequently be found to require 25,791 years for the equinoctial points to perform a complete revolution. At the expiration of half this period, that is, in 12,895 years, the axis of the earth, represented by the line NS, (Fig. 11.) will have altered its position to the line *ns*, and instead of pointing to what we now call the polar star, will be directed to a point in the heavens situated in the constellation Lyra.

In consequence of this slow motion of the earth's axis, the sun comes round from the equinox to the equinox again a little before the earth has completed its annual revolution. Hence arises the difference between the Tropical and the Sidereal year. The *Tropical Year* is the time which the sun takes to traverse the ecliptic from one tropic or equinox to the same again, and consists of 365*d.* 5*h.* 48′ 49″. The *Sidereal Year* is the time which the earth takes to perform a complete revolution in its orbit round the sun, and consists of 365*d.* 6*h.* 9′ 12″. The sidereal year is therefore 20′ 23″ longer than the tropical year.

Another effect of this motion is, that the longitude of every star increases a little every year; for the longitude of a star being its distance from the point of the vernal equinox reckoned on the ecliptic eastward, that distance must of course be increased by the re-

cession of the equinoctial point westward. Hence appears the reason why the signs of the ecliptic do not now correspond in place with the constellations from which they derive their names; for the constellation Aries, which was formerly the place of the vernal equinox, is now 30 degrees eastward of it; and the constellation Taurus is in like manner 30 degrees eastward of the second ecliptic sign called by the same name. Astronomers have thought fit to allow these divisions of the ecliptic to retain their original names, notwithstanding this change of place which the lapse of ages has produced.

The precession of the equinoxes has been very skilfully employed by Sir Isaac Newton in rectifying the system of ancient chronology. For the rate of their retrograde motion being known, whenever their place at any remote period is recorded, or whenever any appearance is mentioned, by means of which it may be ascertained, the date of that period may be calculated, by observing how far the equinoctial points have receded from their then situation to their present, and allowing 72 years to every degree. By this method Sir I. Newton has ascertained the time of the Argonautic expedition, when there is reason to believe the artificial sphere was invented; and the remarkable agreement of all the results obtained from different data, is a convincing proof of the truth of his calculations.*

* See Priestley's Lectures on History, Lect. XII.

CHAPTER XV.

OF THE MOON.

HAVING now considered all the more important particulars which Astronomy teaches respecting the globe which we inhabit, we turn our attention to the other bodies of the system, and that which claims, as being nearest to us, our first notice, is the Moon. The quick motions of this luminary, and the rapid alterations of its appearance, attracted at a very early period the attention of mankind, and furnished the earliest standard for the computation of time. Anciently, in many countries, the periods of new and full moon were celebrated by festivals, and consecrated to the performance of religious exercises. The interval between the changes of the moon gave rise to that division of time which is called a month, which was at first supposed to consist of 30 days; and when the motion of the moon came to be compared with, and adjusted to the motion of the sun, 12 of these months were thought to correspond exactly with the sun's annual course. Some barbarous nations still measure the year by the revolutions of the moon.

This luminary is now known to be the earth's satellite, or a secondary planet which revolves round the earth as its immediate centre, and attends it in its annual journey round the sun. The phases of the

moon, or the changes which regularly take place in the appearance of its disk, prove that it is an opaque body, which shines only by means of light reflected from the sun. When the moon is between the earth and the sun, her darkened side is turned towards us, and consequently she is invisible. In a few days, when she has moved a little to the east, we catch a view of a small portion of her illumined side, which appears in the form of a crescent, the convex side of which is turned towards the west, and the cusps or horns towards the east. After the lapse of about 7¼ days, when she is 90 degrees eastward of the sun, half of her illumined side is visible, and she appears consequently a half moon. As she continues her motion eastward, she presents more and more of her enlightened side to our view; till at the end of 14¾ days, she is directly opposite the sun, and consequently comes to the meridian at midnight, and presents the whole of her enlightened side to view. Moving on still eastward, she goes through the same changes of appearance in a reverse order, till in about 14¾ days from the time of full moon, she again overtakes the sun, and becomes invisible. The entire revolution is performed in 29*d.* 12*h.* 44′ 3″. This period between one new moon and the next is called a ***Lunation*** or ***Synodical Month;*** and it is carefully to be distinguished from another period called the ***Periodical Month,*** which is the time the moon takes to perform her real revolution round the earth, and comprises only 27*d.* 7*h.* 43′ 5″. The reason of this difference may be

understood from Fig. 12. Let S represent the sun, AB a part of the earth's orbit, DM, *dm*, the moon's orbit in two different situations of the earth. The earth being at A, let the moon be supposed to commence its revolution from the point of conjunction, or change, D. If the earth continued in the same place, it is evident that the moon would again be in conjunction at the end of one entire revolution in its orbit. But if, during the moon's revolution, the earth move from A to B, the moon, at the end of her revolution, will be at *d*, a point which is not between the earth and the sun: it must therefore move on from *d* to *e*, before it can again be in conjunction. Hence it is, that the interval between new moon and new moon is somewhat longer than the period of the moon's actual revolution round the earth.

When the moon is at D between the earth and the sun, it is said to be in *conjunction*. When it is at M, it is said to be in *opposition*. At the two intermediate points it is said to be in *quadrature*. These terms are used with respect to all the planets, and are usually expressed by the following symbols.

☌ Conjunction.

☍ Opposition.

□ Quadrature.

A line joining the points of conjunction and opposition is called *the line of the Syzygies.*

The orbit of the moon is elliptical, having the earth in one of the foci; but the eccentricity of this ellipse is variable. The plane of its orbit is inclined to that

of the earth at an angle of about 5° 9′. To illustrate this, let ABC (Fig. 13.) represent a portion of the earth's orbit, and the surface of the paper the plane of that orbit. Then, if another circle, as DEFG, be drawn to represent the moon's orbit, that circle, being in the same plane or surface with the larger circle, will not correctly show the position of the moon's orbit. But if it be supposed to be cut out of the paper, and placed in an inclined position, hinging, as it were, upon the line DF, so that one half, namely, DGF, may rise above the level of the paper, and the other half, DEF, may sink below it, making with the surface of the paper an angle of 5° 9′, as shown by the intersecting lines at H, it will then furnish a just representation of the position of the moon's orbit with respect to the earth's. The points D and F, where the plane of the moon's orbit intersects that of the earth's, are called the *Nodes;* and they are distinguished from one another by the epithets *ascending* and *descending*. The *ascending node*, F, is the point where the moon, moving from west to east, begins to ascend above the level of the earth's orbit: the *descending node*, D, is the point where she begins to descend below that level. The line DF, which joins them, is called the *line of the nodes;* and this line, be it observed, is not always pointed in the same direction; for the nodes shift backward or westward, at the rate of about 19 degrees every year, so that in the course of about five years the line DF will lie in the direction EG at right angles to its former position.

The moon, like the earth, revolves upon her axis, but with a much slower motion, her rotation being performed in 29*d*. 12*h*. 44′ 3″, which is exactly the length of the lunation or synodical month. Hence it is that the same side of the moon is always presented towards the earth. This, however, is subject to a small variation called the moon's *libration*, which is of two kinds.

The moon's *libration in longitude* arises from the circumstance that the periods of her rotation upon her axis, and of her revolution in her orbit round the earth, though completed in exactly the same time, do not correspond in all their parts; her motion on her axis being always uniform, while that in her orbit is variable; the effect of which is, that we see sometimes a little more of her western side, sometimes a little more of her eastern, according as her motion in her orbit is accelerated or retarded.

The *libration in latitude* arises from the moon's axis being inclined to the plane of her orbit; on which account sometimes one of her poles, sometimes the other, is inclined towards the earth, and we see more or less of the polar regions.

The moon's distance from the earth is estimated at about 237,000 miles. This distance is so small, compared with the earth's distance from the sun, the latter being about 400 times the former, that the moon's path in space, resulting from her combined motion round the earth and round the sun, is not a series of looped curves, as might at first be supposed, but a

waving line *always concave to the sun.* To make this curious fact intelligible to the learner, let a circle be described upon a floor, by means of a string 40 inches long, attached at one end to a nail or pin stuck in the floor, and having a pencil at the other end for tracing the circle. Let this large circle represent the earth's orbit round the sun: then, to represent the moon's orbit round the earth in the same proportion, a circle must be drawn with a radius of not more than 1-10th of an inch, this being the 400th part of 40 inches. Let the large circle be divided into 12 equal parts, to represent the portions of its orbit which the earth traverses in a month,* and conceive that, while the earth (represented by a little globe no larger than a grain of sand) moves through one of these portions, the moon (represented by a still smaller globe) performs one revolution round it at the distance of 1-10th of an inch. It will then be understood that the moon's absolute track, if marked upon the floor, would be a waving line crossing the earth's track 12 times, but never coming within it, or going out of it, further than 1-10th of an inch; and if lines be drawn, joining the points of intersection with one another, it will be seen that the moon's track, even when it comes within the earth's orbit, does not reach those lines, and is therefore always concave

* This is not strictly accurate, for, as 12 lunations are completed in 354 days, a 12th part of the earth's orbit exceeds the space traversed in a month in the ratio of 365 to 354. It is, however, sufficiently accurate for the purpose of this illustration.

towards the sun. This fact is well worthy of notice, as serving to convey a just idea of the comparative dimensions of the orbits of the earth and moon, and to correct the misapprehensions which are apt to arise from the false proportions of the diagrams usually employed in explanation of the moon's motions.

The diameter of the moon is estimated at 2180 miles, and her solid bulk is hence found to be about 1-48th part of that of the earth.

The surface of the moon is greatly diversified with inequalities, and when viewed through a telescope presents a most rugged appearance of cavities and mountains. The reality of these is proved more decisively by viewing her at any other time than when she is full; for then the edge or border, which separates the illumined from the darkened portion of her surface, presents a singularly broken and jagged appearance; and even in the dark part, near the borders of the lucid surface, some small detached spots of light may be found, which are evidently the tops of mountains catching the sun's rays, while the lower parts around are involved in shade. In all situations of the moon, moreover, the bright spots are constantly accompanied by a triangular shadow on the side opposite to the sun, while the dark spots have an edge of light on the same side—a circumstance which clearly proves that the former are mountains, and the latter cavities. Astronomers have endeavoured to calculate the height of these mountains, but differ widely in the results they have obtained, some having

CHAPTER XVI.

PROBLEMS RELATING TO THE MOON.

PROBLEM I.

To find the Moon's Place in the Heavens for any given Day and Hour.

In White's Ephemeris will be found a column in which the moon's *longitude*, or place in the ecliptic, is stated for every day in the year; and another adjoining column which shows her *latitude*, or distance north or south of the ecliptic; for the moon's orbit, as already observed, being inclined to the plane of the earth's orbit at an angle of about 5° 9′, her motions in the heavens will range within that limit on each side of the ecliptic.* The point thus determined is the moon's place in the heavens for the *noon* of the given day. But as, by her rapid motion in her orbit, her longitude increases every hour of the day, at the mean rate of 13° 10′ in 24 hours, it is necessary, when the given hour is intermediate between two noons, to calculate how much farther she has advanced. For this purpose, take the difference between her longitude on the given day, and her longitude on the ensuing day:

* The angle varies from 5° to 5° 18′. The latter is, therefore, sometimes the amount of her latitude.

this difference being the amount of her advance in longitude at that time in 24 hours, shows at what rate she is then moving; and from this rate of motion it may easily be ascertained, by the rule of three, how far she has advanced in the interval which has elapsed since the last noon. For example, I wish to find the moon's exact place in the heavens at 10 o'clock in the evening of the 4th of March, 1828. The moon's longitude for that day, as given in the Ephemeris, is 15° 28′ in Libra; and on the following day, 28° 25′ in the same sign: the difference, 12° 57′, is the moon's advance in longitude between the noon of the 4th, and the noon of the 5th of March. Then, by the rule of proportion—

As 24 hours : 12° 57′ : : 10 hours : 5° 23′ 45″.

Thus we obtain the amount of the moon's advance in 10 hours at this period, which being added to 15° 28′, gives 20° 51′ 45″ for her exact longitude at the given hour. Her latitude on the same day, according to the Ephemeris, is one degree south. Thus her precise situation in the heavenly sphere for the given day and hour is determined.

PROBLEM II.

To find the Moon's Situation with respect to the Sun, and the Time of her rising, southing, and setting; also her Meridian Altitude, on any given day.

Having found the moon's place as above, and marked it upon the globe by a small patch, and having also found the sun's place for the given day, as

directed in a former problem, (p. 55.) rectify the globe for the latitude, bring the sun's place to the meridian, and set the index to 12. It may then be observed in what situation the moon is with respect to the sun, whether in conjunction, opposition, or quadrature; and how far advanced in her synodical revolution. If her place be *eastward* of the sun's, it will be observed, on turning the globe westward, that she will rise and set *after* the sun, and afford the benefit of her light in the evening. If her place be *westward* of the sun's, it will be seen that she will rise and set *before* the sun, and be visible only in the early hours of the morning. The patch being brought to the eastern or western side of the horizon, the index will show the hour of her rising or setting. Being brought to the meridian, the time of her southing may in like manner be observed, as also her meridian altitude. Or if we wish to ascertain her situation with respect to the horizon at any given hour, we have only to place the globe so as to represent the position of the heavens at that hour, according to a former problem, (p. 59.) and observe the situation of the patch with respect to the wooden circle.

Here it is not unimportant nor irrelevant to notice the beautiful provision which is made by means of the moon for compensating the long absence of the sun in winter. At the winter solstice the sun is in Capricorn: the full moon, therefore, which happens then, being in the opposite point of the heavens, must be in Cancer. It will, consequently, rise to the same ele-

vation, and describe as large a circuit above our horizon as the sun in summer, thus affording us the longest duration of moonlight at a time when we need it most. On the contrary, at the summer solstice the moon is full in Capricorn: like the sun in winter, therefore, she pays us only a short visit, and rises to a small elevation; but the shortness of the nights enables us at this time to dispense with her light with the least inconvenience. This provision is more remarkable still with respect to the polar regions, where the moon continues above the horizon during half of her monthly revolution. For let the globe be rectified for the north pole, or placed in that position which is called a parallel sphere, (see p. 32.) and let the sun be supposed in the first of Capricorn, which is its place at the winter solstice; it will then appear by inspecting the globe, that the moon will become visible to that part of the world when entering upon her second quarter in Aries, and that she will continue above the horizon during all the period of her greatest illumination, till she enters upon her last quarter in Libra, thus affording to those dreary regions the utmost benefit of her light, at a time when the sun's long absence renders it most necessary.

CHAPTER XIII.

OF THE CALENDAR.

We have seen that the year contains not any exact number of days, but so many days and a certain fraction of a day, (namely, 365*d.* 5*h.* 48′ 49″.) This circumstance occasioned for a long time great perplexity in the computation of the year, and the adjustment of the calendar. The Egyptians, according to Herodotus, were the first who fixed the length of the year, making it to consist of 360 days, which they distributed into 12 months of 30 days each. This computation, by omitting more than five days, would obviously occasion great confusion, and at a very early period it was found, (and the Egyptians claim the merit of the discovery, which they attribute to Hermes or Thoth,) that the duration of the year must be reckoned at 365 days. This, however, still fell short of the true year by almost six hours, so that four Egyptian years would be less than four natural years by almost one whole day. By this omission of one day in four years, the commencement of the civil year would gradually fall back in the natural year, and shift in the course of time through all the seasons. To remedy this great inconvenience, it was enacted authority of Julius Cæsar, that one additional uld be introduced into the calendar every

fourth year, which is called *Bissextile* or *Leap Year*. This additional day is now placed at the end of the month of February, which has, therefore, every fourth year, 29 days instead of 28. But in the ancient Roman calendar, the 6th of the calends of March, corresponding to the 23rd of February, was that year reckoned twice over; hence the year was called *bissextilis*. The term *leap year* is derived from the circumstance of its causing the numbers of the days of the month to fall a day later in the week than they otherwise would. For as the ordinary year of 365 days contains 52 weeks and one day more, the number of the month, instead of remaining fixed to the same day of the week, shifts ordinarily to the following day; but when a leap year occurs, which contains two additional days, the number of the month is removed *two days* onward in the week. Thus, if the 1st of March in one year fall on Monday, it will fall the next year on Tuesday; but if it be a leap year, it will leap or pass over Tuesday, and fall on Wednesday.

This method of computing the year being introduced and established by Julius Cæsar, is from him called the Julian calendar. We must now, however, proceed to observe, that the Julian calendar proceeds upon the assumption that the natural year is 365 days 6 hours exactly; but the truth is, it falls short of that time by 11 minutes and 11 seconds. In the period, therefore, of 129 years, there would be a difference between the Julian and the true reckoning, of about *one day*. To rectify this error, and to keep the be-

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shadow, the moon appears for a few moments like a dark round spot covering the centre of the sun, but leaving its outer edge visible in the form of a luminous ring. This phenomenon, which is of very rare occurrence, is called an *annular* eclipse, from *annulus*, the Latin word for *ring*. But though, according to what has just been observed, an eclipse of the sun can never be seen *total* at the same instant over a greater extent of the earth than a space of 180 miles in breadth, yet the same eclipse may be seen *partially* to a wider extent. For the moon's proper shadow is surrounded, as shown in the figure, by a fainter diverging shadow, called the *penumbra*, bounded by lines from the extremities of the sun's disk touching the alternate sides of the moon. To all inhabitants of the earth who are within this penumbra, but out of the limits of the dark shadow, the moon's body will intercept from view a part only of the sun's disk, and the further a spectator is situated within the bounds of the penumbra, the greater will be the portion of the sun's body hidden from his view. The breadth, however, of the penumbra never much exceeds half the earth's diameter; so that an eclipse of the sun may often happen without being seen by many even of those inhabitants of the earth who have the sun at the time above their horizon: on the contrary, an eclipse of the moon cannot happen without being visible at once to all that hemisphere of the earth which is turned towards the moon during the eclipse.

The usual number of eclipses in the year is four,

two of each luminary; for in the course of the revolution of the earth and moon round the sun, each node must be presented once at least to the sun, and on these occasions an eclipse of each luminary *may*, and usually *does*, take place. But there is this difference between the sun and moon, that on these occasions there *must* be an eclipse of the former, and there *may* be none of the latter; for the limits within which a solar eclipse may take place, are, as before stated, 17 degrees on each side the node, making an extent of 34 degrees altogether; and as the sun, in its apparent annual revolution round the earth, takes more than a month to traverse this space,* the moon *must* come between the earth and sun while the sun is within these limits; but the limits within which a lunar eclipse may take place, are only 12 degrees on each side the node, or 24 degrees in all; and as the sun takes less than a month to move through that portion of its apparent orbit, it is possible for one opposition to take place a little *before* it gets within these limits, and the next a little *after*. If, therefore, there are only two eclipses in the year, they must both be solar eclipses.

Sometimes, however, there are six eclipses in the year, and this may happen in two ways. First, an

* The effect is precisely the same, whether the earth revolve round the sun, or the sun round the earth; but, though the real motion is in the earth, the present subject will perhaps be better understood, if the sun be conceived as revolving round the earth in an orbit which includes the moon's.

eclipse of the sun may take place just after the sun has entered the solar ecliptic limits, in which case the moon will come round again to the point of conjunction, and cause a second eclipse, a little before the sun has left those limits,* and in the mean time it will itself suffer an eclipse at the time of opposition. Thus at each node there may be two eclipses of the sun, and one of the moon, making four of the sun and two of the moon in the course of the year; but in this case the solar eclipses will be small, by reason of the sun's distance from the node; and the lunar ones large, because they will take place at or very near the node. The six eclipses may happen also in another manner, thus: It has been observed that the nodes of the moon's orbit are not stationary, but move backward or westward at the rate of about 19 degrees in a year. By reason of this, it is possible for one of the nodes to be presented to the sun twice in the year, for by moving in a direction contrary to the sun's apparent annual motion, they come, as it were, to meet the sun, so that the sun returns to the same node as many days before the end of the year, as it would take to move through 19 degrees, that is, about 19 days. Thus, in the course of the year, three of those occasions are afforded on which an eclipse of each luminary may take place, so that there may be three eclipses of the sun, and three of the moon.

* For the time of one lunation is five days less than the time which the sun takes to move through 34 degrees.

But if, when the two nodes are presented once only to the sun, three eclipses may take place at each, making six in the course of the year, why may there not be *nine* eclipses in the year, in the case when one of the nodes is presented to the sun a second time? This cannot be, because, as before observed, the case of three eclipses happening at each node requires that the sun should be only just entered within the solar ecliptic limit at the commencement of the year, and in this case, though, by reason of the retrograde motion of the nodes, he may again enter the same limit before the end of the year, and cause a fifth solar eclipse, yet this must happen so late in the year as not to allow of a lunar eclipse after it: for a fifth solar eclipse can happen only at the end of 12 lunations, or at the last change of the moon comprised within the year; and 12 lunations, or 354 days, leave only 11 days to the end of the year, which time is not sufficient for the moon to come round again to the point of opposition, where it must be in order to suffer an eclipse. The greatest possible number of eclipses, therefore, which the year can comprehend, is seven, namely, five of the sun and two of the moon.

CHAPTER XVIII.

OF THE TIDES.

BESIDES occasioning the striking phenomena of eclipses, the moon is the chief agent in producing a more ordinary, but not less wonderful effect, which we observe in the alternate flux and reflux of the ocean. The ancients had remarked that these motions of the ocean were in some way connected with the moon; but the first who clearly demonstrated the cause of this phenomenon was Newton. He has shown it to be one of the effects of that great law of attraction which pervades the universe, the sun and moon, but chiefly the latter, being the attracting powers which act upon the ocean. To illustrate this subject, let us suppose the earth to be entirely covered with water, as represented in Fig. 16. Then, supposing no other body were near to disturb the force of gravitation, the waters would be every where equally attracted towards the centre of the earth, and would, therefore, form an exact spherical surface. But let the moon, M, be placed at such a distance as to exert her attractive influence upon the waters, and they will be drawn towards her, and rise above their level at Z; while the waters at A and D will be drawn away to supply the redundancy at Z, and at those places it will be low water. But it is known

by experience that when the waters at Z are elevated, those in the opposite point N are likewise elevated; for we have high water twice in every diurnal revolution of the moon. In order to account for this, it is necessary to observe that the power of gravity, by an universal law, diminishes as the square of the distance increases. The waters, therefore, at Z, will be more strongly attracted by the moon, M, than the centre of the earth, C, the effect of which will be, that the distance between Z and C will be increased, and the waters at Z will rise. The centre C, likewise, being nearer the moon than the waters at N, will be more strongly attracted, and the effect will be, that the waters at N will *gravitate with less force* towards the centre, and will consequently rise above their natural level. Thus it is that the moon's attractive power produces a tide at each of the two opposite points Z and N at the same time. These tides succeed each other at intervals of 12 hours 24 minutes, for, as before observed, there are two tides in each diurnal revolution of the moon, which revolution, by reason of her rapid motion in her orbit, occupies 24 hours 48 minutes. It should, however, be observed, that high water does not take place precisely at the time of the moon's passing the meridian, but usually about three hours after, the impulse of the moon's attraction requiring that time to produce its full effect upon the waters. Add to this, that various local circumstances delay the tides, so that at some places the interval between the moon's coming to the meridian, and the

tide which she produces, is considerably greater than that which has been mentioned.

But the sun has also some degree of influence in the production of the tides, though less than that of the moon, on account of his greater distance; and hence may be derived an explanation of the difference in the height of the tides at different periods. Sir Isaac Newton has computed that the force of the moon is adequate to raise the waters in the ocean 10 feet, whereas that of the sun is adequate to raise them only 2 feet. Now at the new and full moon these forces of the sun and moon act in concurrence, and their joint power will be equal to the sum of the separate powers, that is, it will raise the waters 12 feet. But when the moon is in quadrature, their forces counteract each other, and the effect produced upon the tides will be equal to the difference of the separate forces, that is, the tides will be raised only 8 feet. The former are called *spring tides*, the latter *neap tides*, each of which happens every fortnight, because that is the interval between new and full moon. The spring tides themselves, moreover, are greater at some times than at others; the reason of which is, that the sun and moon, from causes already explained, are not always at the same distance from the earth, and that the moon, when in the equator, produces a greater swell, by reason of the earth's spheroidal form. The highest tides are those which happen a little *before* the *vernal*, and a little *after* the *autumnal* equinox; that is, *about the time of each*

equinox, because the moon is then in the equator, but on the *winter side* of each, because the earth is nearer to the sun, and the sun's attractive power, therefore, is greater in winter than in summer. It should be observed, however, that both the height of the tides and the time of their happening, are much affected by various local circumstances, such as shallows, rocks, islands, and narrow passages, which often produce results differing very widely from the theory. The tide is in general found to rise highest in long channels or inlets of the sea, which present a wide entrance towards the ocean, but gradually contract to a narrow passage. Such is the Severn, where the tide rises to a height of 30 or 40 feet. At St. Malo, from a like cause, the height of the tides is 50 feet, and at Annapolis, in the Bay of Fundy, as much sometimes as 100 feet. But in seas confined within land, and communicating with the ocean only by a narrow strait, such as the Baltic and the Mediterranean, the tides are scarcely perceptible, because their narrow inlets do not admit of so quick a reception and discharge of water. The tides, moreover, happen at various hours in different places; for they may be considered as great waves, generated by the influence of the moon in the wide ocean, and rolling thence in various directions along the coasts of the continents, filling the bays and rivers successively in their progress. The tide generated in the Atlantic ocean, corresponds, in point of time, to the general law already stated; for it is high water on the coasts of Spain, Portugal, and

the west of Ireland, about the third hour after the moon has passed the meridian. But on reaching the British islands, it is divided into three streams, one of which flows up the English Channel, another up St. George's Channel, and the third round the north of Ireland and Scotland. The first reaches Plymouth 6 hours after the moon has passed the meridian, Portland 8¼ hours, Dover 11½ hours, and the Nore 12 hours. The second, which flows through St. George's Channel, arrives at Cork 6½ hours after the moon has passed the meridian, at Dublin 9¼ hours, at Liverpool 11¼ hours; while the stream which flows round by the north of Ireland and Scotland, arrives from the Atlantic at Caithness Point in 9 hours from the same period, at Aberdeen in somewhat less than 13 hours, at Flamborough Head in 16 hours, at Yarmouth in about 22 hours, and at the Nore in 24, where it meets the first stream which came from the Atlantic up the English Channel in 12 hours. In long rivers there are sometimes two or more tides pursuing one another at different points along their channel. Thus in the great river Amazons, the tides are perceived at Pauxis, 500 miles from the sea, after an interval of several days spent in their passage up; and within this space, it is said, there are not less than seven tides following one another at regular distances at the same time.

CHAPTER XIX.

OF THE HARVEST MOON.

As the moon moves towards the east at the rate of about 13° a day, the time of her rising is about 50 minutes later on an average every successive day. At the equator this is uniformly the difference in the time of her rising; but in places of considerable latitude, the intervals between her times of rising vary from 17 minutes to 1 hour 15 minutes. This is owing to the different angles which the moon's path makes with the horizon; for as the moon's path nearly coincides with the ecliptic, it will be seen, by inspeeting the globe, that that part of her path which is adjacent to Aries, makes a much more acute angle with the eastern horizon, than that which is adjacent to Libra. The consequence of this is, that the former part rises much more rapidly than the latter; and therefore the same advance of the moon in the former part makes a much less difference in the time of her rising than in the latter. To illustrate this, let small patches of paper be fixed at the distance of every 13 degrees on the ecliptic of a celestial globe, to represent the moon's situation on successive days. Then, the globe being rectified for the latitude of the place, by turning it westward, it will be seen that the marks in Pisces and Aries appear above the eastern side of the horizon

in very quick succession, while those in Virgo and Libra appear with more considerable intervals, which shows that the same advance of the moon in her orbit makes a much smaller difference in the successive times of her rising in the former situation than in the latter. Now the former is the situation of the full moons which happen in autumn, because the sun being then in the signs Virgo or Libra, the moon at the time of her opposition will be in Pisces or Aries. The full moon thus rising for several successive evenings nearly at the same hour, that is, at intervals of a quarter of an hour, during the period of harvest, is called the *Harvest Moon*. The same circumstance in her time of rising must happen, be it observed, every month, because every month she passes through the signs Pisces and Aries; but as it is only in autumn that it coincides with the time of full moon, it is only then that the phenomenon is particularly remarked.

CHAPTER XX.

OF THE SUN.

THAT body in the system which next claims our attention, is the Sun. It has already been shown that this great luminary is situated in the centre of the system to which our planet belongs, and is the source of light and heat to the whole; and its apparent diurnal and annual motions have been accounted for by the real diurnal and annual motions of the earth. It only now remains, therefore, to state some particulars relating to its bulk, and its real motion upon its axis. Its diameter is estimated at about 883,000 miles, which is more than 111 times the diameter of the earth. In solid dimensions, therefore, it is more than a million times larger than the earth.* It revolves upon its axis in about 25 days 10 hours. This fact has been determined by means of certain spots which have been observed on the sun's disk, which first make their appearance on the eastern side, then by degrees advance towards the middle, and so pass on till they reach the western edge, and then disappear. When

* Spheres and all other regular and similar solids are to each other as the cubes of their diameters. The diameters, therefore, of the earth and sun being as 1 to 111, their solid dimensions will be as 1 to 1,367,631.

they have been absent for nearly the same period during which they were visible, they appear again as at first, finishing their *apparent* circuit in 27*d.* 7*h.* 37′, which, allowing for the earth's advance during that period in the same direction, gives 25*d.* 10*h.* for the time of their *real* revolution. The sun's axis makes an angle of 7° 20′ with a perpendicular to the plane of the earth's orbit.

Various have been the speculations of astronomers respecting the cause and nature of those spots which have been mentioned as appearing occasionally on his disk. The opinion of Dr. Herschel is, that this great luminary, which we are prone to consider as a vast mass of fire, is an opaque body, like the earth and planets, but surrounded by a sort of luminous atmosphere, which is the source of light and heat to the planetary system, and that the spots in question are nothing else than *openings in this luminous atmosphere,* which afford us a view of the sun's dark body underneath. But this opinion, though sanctioned by so high a name, and therefore entitled to some attention, can be considered only as a conjecture; and perhaps the subject itself is one of those on which we must for ever remain in ignorance.

CHAPTER XXI.

OF THE INFERIOR PLANETS.

THE planets Mercury and Venus are called *inferior* planets, because their orbits are included within that of the earth. This is evident from their appearances and motions; for they are never seen in opposition to the sun, nor even in quadrature, but accompany the sun in his annual course, moving alternately to the east and west of him, but never exceeding a certain limit, which is called their *greatest elongation*. When they are to the eastward of the sun, they rise and set after him, and, if sufficiently distant from him, may be seen in the evening a little after sunset: they are then called *evening stars*. When they have attained their greatest elongation eastward, they appear for a time stationary, and then begin to retrograde or move backward towards the west. When they have passed the sun, and reached a sufficient distance to the west, they rise and set before him, and being visible only in the morning before sunrise, are then called *morning stars*. Having reached the same elongation or distance from the sun in this direction, they again seem stationary, till they have resumed their direct motion towards the east, when they again pass the sun, and appear eastward of him as before. These appearances will be easily explained by referring to Fig. 17. Let S re-

present the sun, E the earth, ABCD the orbit of an inferior planet, and KF a portion of the starry sphere. At A the planet is viewed along the line EA, and appears in the heavens at F, while the sun is viewed along the line ES, and appears in the heavens at G. This, then, is the situation of the planet when at its greatest elongation westward, for it evidently cannot go in that direction beyond the limits of the line EF; and its motion in its orbit at this point, being nearly in a direct line from the earth, will cause for a while no perceptible change in its apparent place in the heavens. Hence it is that the planet, when at its greatest elongation, appears for a time stationary. Moving on in its orbit from A to B, it will appear to approach the sun, and when arrived at B, supposing the earth to have remained stationary at E, it will be in a direct line beyond the sun, and therefore invisible. Here it is said to be in its *superior conjunction*. When arrived at C, supposing still the earth to be stationary, it will appear in the heavens at H, at its greatest elongation eastward; and here, again, its motion, being nearly in a direct line *towards* the earth, will be scarcely perceptible. Moving from C through D to A, it will appear to retrograde in the heavens from H to F, and at D it will again be in the same direction as the sun, in what is termed its *inferior conjunction*. When arrived at A, it will be, as before, at its greatest elongation westward. Thus if the earth were stationary at E, the planet, by its motion round the sun, would always appear to traverse the same arc in the heavens, going

backwards and forwards continually between the same limits H and F. But as the earth has also a motion in its orbit in the same direction with the planet, though slower, the points of the planet's stationary appearances are continually removed farther and farther towards the east, and its eastward or direct motion is continued longer and farther than its westward or retrograde. Thus, if the earth move from E to I, while the inferior planet moves through the more remote part of its orbit, the place of its stationary appearance on the eastward side of the sun will evidently be removed as far as K; and if the earth's place be changed to L, while the planet describes the nearer part of its orbit, the planet will appear to have retrograded only as far as M. The inferior planets, being never in opposition, never appear full-orbed or round, but show only a part of their enlightened side, sometimes like a half-moon, sometimes in the form of a crescent. These appearances, however, are visible only by the aid of a telescope.

Of the two inferior planets, *Mercury* is that which revolves nearest the sun. He is distinguished by a bright white light; but is generally so near to the sun, as to be seldom seen, his greatest elongation being 28 degrees, 20 minutes.* His distance from the sun is computed at 37,000,000 miles, and the time of his

* It should be observed, however, that the planet does not always recede quite to this distance from the sun before it begins to return. Its elongation varies from 18 to 28⅓ degrees, and this is owing to the elliptical form of its orbit. A similar remark may be applied to Venus.

periodical revolution, or the length of his year, is 87 days 23 hours. He is the least of all the primary planets, his diameter being 3,224 miles, and his magnitude about 1-16th of the magnitude of the earth. But being seldom seen on account of his nearness to the sun, and no spots appearing on his surface or disk, the time of his diurnal rotation and the inclination of his axis to the plane of his orbit, are not fully ascertained.* His orbit is inclined seven degrees to the plane of the earth's orbit. Thus, in Fig. 18, let the outer circle represent the earth's orbit, the plane of which is the surface of the paper; then the inner circle ABCD, if it be supposed raised on one side, and depressed on the other, may represent the orbit of Mercury, the inclination of which is shown by the intersecting lines below, where the two orbits are supposed to be seen edgeways. A is the ascending node, which is directed towards the 15th of Taurus; C the descending node, which is of course directed to the opposite point in the heavens, namely, the 15th of Scorpio. When Mercury is in either of these nodes at the time of his inferior conjunction, that is, when he passes between the earth and the sun, he appears like a dark round spot crossing the sun's disk. This phenomenon is called a *transit*, from the Latin word *transitus*, a crossing or passing over. His conjunctions, when not in the node, are invisible, because he passes either above or below the sun. The light and heat which this planet

* According to Schroeter, he revolves in 24*h*. 5′ 28″.

receives from the sun, are computed to be about seven times more than the earth receives.

Venus, in her appearance to us, is the brightest and largest of all the planets, and when viewed through a telescope, she is seen, like Mercury, with all the various phases of the moon. Her greatest elongation, or apparent distance from the sun, is 47° 48′. When she appears west of the sun, she rises before him in the morning, and was then called by the ancients, Phosphorus, Lucifer, or the Morning Star; and when she appears to the east of the sun, she shines in the evening after he is set, and was then called by the ancients, Hesperus, or the Evening Star; being in each situation alternately for 290 days.* The time of her apparent revolution round the sun is therefore 290*d*. x 2, or 580 days; but her actual revolution is performed in 224 days 17 hours, for the earth going round the sun in the same direction with Venus, though at a slower rate, causes her revolution to appear longer than it really is. The distance of Venus from the sun is computed to be 68,000,000 miles; her diameter 7687 miles.† Her diurnal rotation upon her axis is

* "The Evening and Morning Star, or the Hesperus and Phosphorus of the Greeks, were at first supposed to be different. The discovery that they are the same is ascribed to Pythagoras."—Playfair's Outlines of Natural Philosophy, vol. ii. p. 157.

† This is the common estimate; but according to the recent observations of Dr. Herschel, the diameter of Venus somewhat exceeds that of the earth, being 8648 miles.—See Brewster's edition of Ferguson's Astronomy, vol. ii. p. 108.

performed in 23 hours 21 minutes. Her orbit is inclined to the plane of the ecliptic at an angle of 3° 23′. The position of her axis with respect to her own orbit is not ascertained. Transits of this planet also take place in circumstances similar to those of Mercury; that is, when the time of her inferior conjunction coincides with that of her being at or near the node; but this is a conjuncture which rarely happens. The last transit of Venus was in 1769; the next will not take place till 1874.

CHAPTER XXII.

OF THE SUPERIOR PLANETS.

THE Superior Planets are those which revolve round the sun at a greater distance than the earth, and whose orbits, therefore, include that of the earth. This is evident from the fact that they are often seen in opposition. Their apparent motions in the heavenly sphere are similar to those of the inferior planets; that is, they sometimes move eastward, which is called their direct motion, sometimes westward, when they are said to be retrograde, and appear stationary at each change of their direction; their eastward or direct motion being always continued longer and further than their westward or retrograde. The explanation, how-

ever, with respect to them is somewhat different from that which has already been given with respect to the inferior planets. Let E, (Fig. 19.) represent the earth in its orbit, M, Mars or any other superior planet in its orbit, and AC, a portion of the apparent sphere of the heavens. While the earth moves from E through D to *e*, the planet M, supposing it to be stationary at that point, would appear to move backward in the heavens from B to A; and by the earth's motion through the remainder of its orbit *e*FE, the planet would appear to return from A to B again. At each change of its direction, also, the planet M would appear stationary, because the earth at E is moving nearly in a direct line *towards* the planet, and at *e* nearly in a direct line *from* the planet. It is then evident that, if the planet were stationary at M, it would nevertheless appear, in consequence of the earth's motion, to move backwards and forwards in the heavens between the limits A and B. The planet, however, not being stationary, but moving in the same direction with the earth, though much more slowly, the effect is, that it moves further eastward than westward, and the points of its stationary appearances are continually removed further towards the east. Thus, if, while the earth moves in its orbit from *e* through F to E, the planet also moves from M to *m*, it will appear to have advanced in the heavens from A to C; and as the planet continues its eastward motion, while the earth describes the nearer part of its orbit, from E through D to *e*, its apparent retrograde motion will

be thereby retarded and shortened, so as not to extend so far as the point G.

The Superior Planets are eight in number, namely, Mars, Vesta, Juno, Ceres, Pallas, Jupiter, Saturn, and Uranus.

Mars is distinguished from all the other planets by his dusky red colour, which is supposed to be owing to his being encompassed with a dense atmosphere. He appears much larger when in opposition than when near his conjunction, because in the former case he is nearer to the earth, by the entire diameter of the earth's orbit. His apparent diameter in opposition is 17 seconds; in conjunction only about 4 seconds. His distance from the sun is 144,000,000 miles, his diameter 4189 miles, and his magnitude about 1-7th of that of the earth. He revolves on his axis in 24 hours 39 minutes, and performs his revolution round the sun in 1 year 321 days 22 hours. The inclination of his orbit to the plane of the ecliptic is 1° 51′, and the place of his ascending node about 18° in Taurus. The inclination of his axis to the plane of his own orbit is 59° 22′, that is, 30° 38′ from the perpendicular, so that this planet has a change of seasons similar to that of the earth.

Between the orbits of Mars and Jupiter revolve four small planets, invisible to the naked eye, which have been discovered only since the commencement of the present century. They have received the names of *Vesta*, *Juno*, *Ceres*, and *Pallas*. The size of the two former is not ascertained, but the diameter of Ceres,

according to Herschel, is only 162 miles, and that of Pallas 147. They revolve at no great distance from one another, between the limits of 225 and 263 millions of miles from the sun, in orbits so eccentric that they cross one another. They are remarkable also for the great inclination of their orbits to the plane of the ecliptic; that of Pallas having an inclination of 34½ degrees, which is far beyond the limits of the zodiac.

Jupiter, the next planet in the system, is conspicuous in the heavens by his size and brilliance, being inferior in these respects to none but Venus. In real size, however, he is by far the largest of all the planets, his diameter being not less than 89,170 miles, and his magnitude 1400 times that of the earth. His distance from the sun is 490,000,000 miles, and he performs his revolution in 11 years 315 days. His diurnal rotation is remarkably rapid, being completed in 9 hours 56 minutes; and it is owing probably to this rapid motion, that his figure is much more oblate, or flattened at the poles, than that of the earth. His axis is nearly perpendicular to the plane of his orbit, so that he has no diversity of seasons. The inclination of his orbit to the plane of the ecliptic, is 1° 19′, and the place of his ascending node about 8° in Cancer. When viewed through a telescope, he appears surrounded by faint streaks called zones or belts, the nature or cause of which is wholly unknown.

Jupiter is attended by four satellites, or secondary planets, which revolve round him as the moon re-

volves round the earth, but with much greater rapidity. Their distances and periodic times are as follows:—

Satellite.	Distance from Jupiter.	Periodic Time.			
1st.	254,000	1*d*.	18*h*.	27′	33″
2d.	404,000	3	13	13	42
3d.	644,000	7	3	42	33
4th.	1,134,000	16	16	32	8

These satellites are invisible to the naked eye. They were discovered by Galileo, in the year 1610, immediately after the invention of the telescope, and by him were called the Medicean stars, in honour of the house of Medici. These satellites are subject to frequent eclipses analogous to those of our moon, and the observation of these eclipses is important, as affording the means of ascertaining the longitudes of places on the surface of the earth, the method of doing which is as follows.

The times of these eclipses being first calculated for the meridian of Greenwich, and stated in the Ephemeris or Nautical Almanack, the observer on an unknown meridian, has only to notice the time at which an eclipse appears to him, and by comparing this time with that at which the eclipse is visible at Greenwich, he obtains the difference of time between Greenwich and the place where he is situated, and from this difference of time he may easily calculate, in the manner already mentioned, his longitude. Thus, if the observer witnesses an eclipse of a satellite at 11 o'clock at night, and finds by the Ephemeris that the same eclipse is visible at Greenwich at 12, he

knows that the longitude of the place of observation is 15 degrees west. This is one of several methods by which longitude may be ascertained; but owing to the nicety of observation which it requires, it cannot be much practised at sea.*

By means of these eclipses another important fact has been ascertained, namely, the progressive motion and velocity of light. It was formerly believed that light traverses space instantaneously; but when it was observed that the eclipses of Jupiter's satellites happen sooner than the computed time when the earth is nearest to Jupiter, and later than the computed time when the earth is most remote from Jupiter, it was inferred that the rays of light require a perceptible time to traverse this difference of space. The times of the eclipses being computed for the earth's mean distance from Jupiter, which is nearly the same as the sun's distance, it is found by repeated observations,

* Any other celestial phenomenon which is seen at the same instant of *absolute* time on different meridians, and the time of which can be calculated for a particular meridian, will equally well answer the purpose of ascertaining the longitude: such are eclipses of the moon; but as these occur but seldom, they are of little practical use to the navigator. The phenomena most useful to the navigator are occultations of stars by the moon, and distances of the moon from either the sun or any remarkable fixed star, called *lunar distances*. These are seen *nearly* at the same instant of absolute time, on different meridians, and, with certain allowances and corrections, afford an almost constant means of ascertaining longitude.

that when the earth is exactly between Jupiter and the sun, the eclipses are seen 8¼ minutes *sooner* than the time calculated; and that when the earth is in the opposite point of its orbit, most distant from Jupiter, they happen 8¼ minutes *later* than the time calculated. Hence it is inferred that light takes about 16½ minutes to travel across the earth's orbit, which is a distance of 190,000,000 miles;* for if the effects of light were instantaneous, the eclipses would be seen at the same instant in every point of the earth's orbit.

Saturn shines with a pale, feeble light, and may be seen, like Jupiter and Mars, in any quarter of the heavens. He revolves round the sun at the distance of 900,000,000 miles, and finishes his revolution in 29 years, 161 days. His diameter is 79,042 miles, and his magnitude nearly 1000 times that of the earth. He revolves upon his axis in 10 hours 16 minutes. The inclination of his orbit to the plane of the ecliptic is 2° 29′, and the place of his ascending node about 21° in Cancer. This planet, when viewed through a telescope, always engages attention by the singular appearance of two concentric rings surrounding the body of the planet, without touching it. The breadth of the inner ring is estimated at 20,000 miles; that of the outer at 7,200, and that of the vacant space between them at 2,839 miles. These rings revolve round the axis of Saturn, and in the plane of his equator, in 10 hours 32 minutes. Various conjectures have been

* This is a velocity of nearly 200,000 miles per second.

formed, but nothing is known with certainty, respecting the nature and properties of these rings. The disk of Saturn, like that of Jupiter, appears crossed by faint streaks or belts, and its form is even more oblate than that of Jupiter, its polar diameter being to its equatorial in the proportion of 11 to 12. This planet is, moreover, attended by seven moons or satellites, which, with one exception, revolve in the same plane with the ring, in orbits inclined to that of Saturn at an angle of about 30 degrees.

The most remote of all the known planets belonging to the solar system was discovered at Bath by Dr. Herschel, on the 13th of March, 1781. It was named *Georgium Sidus* by its discoverer, in honour of the king; but by foreigners it is more commonly known by the name of the *Herschel Planet*, or *Uranus*. It is invisible to the naked eye, but when viewed through a telescope of small magnifying power, it appears like a star of the sixth or seventh magnitude. Its distance from the sun is estimated at 1,800,000,000 miles, and its periodic revolution is performed in about 84 of our years. Its diameter is 35,112 miles, and its magnitude 87 times that of the earth. The time of its rotation upon its axis has not been ascertained. The inclination of its orbit to the ecliptic is 46 minutes 20 seconds. This planet is attended by six satellites, which revolve round it in orbits nearly perpendicular both to its own orbit and to that of the earth.

PROBLEMS RELATING TO THE PLANETS.

PROBLEM I.

To find the Place of any Planet in the Heavens, at any given time.

Find the planet's longitude by means of an Ephemeris; then its latitude; and thus its place on the celestial sphere will be determined.*

PROBLEM II.

To find the Time of any Planet's Rising, Setting, and Southing.

Find the place of the planet as above, mark that place on the celestial globe, and then proceed as in the case of the moon. See page 91.

PROBLEM III.

To find what Planets are visible at any given hour.

Place the globe so as to represent the situation of the heavens at the given hour, by a former problem, (see page 59,) and by consulting an Ephemeris, it will be found what planets are then in the visible hemisphere.

* In *White's Ephemeris*, the tables showing the longitudes of the planets for every day of each month, will be found on the right-hand page; and the tables of latitude at the top of the same page, but only for *every seventh* day, as the latitude varies much more slowly than the longitude.

PROBLEM IV.

To represent, by an Orrery or Diagram, the true Situation of the Planets with respect to the Sun, at any given time.

In *White's Ephemeris*, besides the tables of longitude, mentioned above, there will be found, at the foot of the left-hand page, a set of tables showing the *Heliocentric* longitudes of the earth and other planets for every seventh day. By the *Heliocentric longitude* of a planet is meant the place in which it would be seen in the heavens *if viewed from the sun*. The longitude spoken of in the first problem is the planet's place *as seen from the earth*, and is sometimes called, by way of distinction, the *Geocentric longitude*. Find, then, in the table, the heliocentric longitudes of the several planets on the day nearest the given day, and place their representatives in the orrery accordingly, by means of the ecliptic signs which will be found in its circumference. Or, in lieu of an orrery, construct a diagram representing the several orbits of the planets, at their proportional distances from the sun, and surround the whole by a larger circle, which divide into twelve equal parts, marking them with the signs of the ecliptic, and subdividing them into degrees, as in the wooden horizon of the globe. Then, having found by the table the heliocentric longitude of the earth, and marked it upon the outer circle, lay a ruler from that point to the sun's place, and mark where it crosses the earth's orbit. Proceed in the same manner with the

other planets, transferring the longitude of each to its own orbit; and the points thus marked upon the orbits of the planets will show their true relative situation in the solar system at the given time.

CHAPTER XXIII.

OF THE DIMENSIONS OF THE SOLAR SYSTEM, AND THE MODE OF ASCERTAINING THEM.

In the foregoing account of the solar system, the distances and dimensions of the planets have been stated, without any attempt being made to show the truth of the statements, or the means by which such information has been obtained. On this subject, however, the learner will naturally feel some curiosity; for certainly there is no attainment of human ingenuity more wonderful than that a being so diminutive, and confined to so narrow a corner of the great universe, should have succeeded in measuring magnitudes and distances so far beyond his grasp or reach. The subject, indeed, cannot be fully treated of, without entering into mathematical investigations which would be unsuitable to those for whom this treatise is designed. Nevertheless, to those unversed in mathematics, some information on it may be conveyed, which, while it serves to gratify a laudable curiosity, may excite a

desire to enter more deeply into these interesting studies.

The measurement of all inaccessible distances is accomplished by means of that branch of mathematical science which is termed Trigonometry; and the principle of the whole process is simply this,—that when the dimensions of one side and two angles of a triangle are known, the dimensions of the remaining sides may be found by calculation. Let A, Fig. 20, be any terrestrial object, the distance of which from the point B, I wish to ascertain, but which is so situated, that I cannot conveniently measure that distance in a direct way along the line BA. Instead of this, therefore, I measure a line BC more conveniently situated, and at the two extremities of this *base*, I observe, with an instrument adapted for the purpose, the respective bearings of the object A, that is, the angles CBA and BCA; and these data, namely, the length of the base BC, and the number of degrees contained in the angles CBA and BCA, furnish all that is required for calculating the length of either of the other sides of the triangle.

The base employed in ascertaining the distances of the heavenly bodies is the earth's *semidiameter*, which has been previously found, in the manner explained in a former chapter. The angle which this base subtends, or is opposite to, when lines are drawn from its extremities to any heavenly body, is called the *Parallax* of that heavenly body, from a Greek word signifying *a change of place*, because it is the measure

of the difference between the apparent place of the body as seen from the surface of the earth, and the place in which it would appear, if seen from the centre. Let A, Fig. 21, represent the earth, M the moon in her orbit, and GD a portion of the heavenly concave. A spectator situated on the earth's surface at A, will view the moon along the line AM, and refer it to the point H in the heavenly sphere; but if he could view it from the earth's centre, it would appear in the direction of the line CM, and be referred to the point G in the sphere of the heavens. The difference between these two places, namely, the arc GH, or what is equivalent to it, the angle GMH, or AMC, formed by these different lines of view, is the moon's parallax. The effect of parallax, then, is to *depress* the place of a heavenly body, or to make it appear lower than it really is; and this depression is greater the nearer the body is to the horizon. When a heavenly body is in the zenith, it has no parallax, for then the lines drawn to it from A and C coincide. But when the heavenly body is in the horizon, as at *m*, the angle of parallax, A*m*C, is the greatest possible; in which case it is called, by way of distinction, the *horizontal parallax*.

A little consideration will make it evident, that the nearer any heavenly body is to us, the greater must be its parallax; and as the moon is the nearest of all the heavenly bodies, her horizontal parallax is considerable, and has been ascertained with the greatest precision. Various methods have been employed for this pur-

pose; but the simplest and most intelligible is the following. Let A, as before, (Fig. 21,) be the place of an observer upon the earth; AB his sensible horizon; CD his rational horizon; Z his zenith, and ZE a portion of the moon's orbit. In moving from Z to *m*, the moon appears to the observer at A to traverse a quarter of her diurnal revolution, because at *m* she appears on his sensible horizon; but in reality she does not complete a quarter of her revolution till she arrives at E, on his rational horizon. Now the time she takes to move through the quadrant from Z to E, is known, being a fourth part of the time of her entire diurnal revolution, which is 12 hours 48 minutes; and as the time she takes to move from Z to *m* is found by observation, the difference of these periods, or the interval between her arrival at *m* and her arrival at E, is easily ascertained. Then, by the rule of proportion, we say, As a fourth part of 24 hours 48 minutes is to this interval, so is the quadrant ZE, or 90 degrees, to the arc *m*E, which measures the angle *m*CE, and this angle, according to a well known property of parallel lines, is equal to the angle of parallax A*m*C.* In the triangle A*m*C, then, we have the measure of the angle A*m*C thus found: the angle CA*m* is also known, because, by the nature of the problem, it is a right angle; and the side AC is known, being the earth's semidiameter. We have, therefore, all the data necessary for computing the side C*m*, which is the distance of

* See Euclid, Book I. Prop. 29.

the moon from the centre of the earth. The moon's horizontal parallax varies a little according to her varying distance from the earth; but taken at a mean, it is about 57 minutes, or very nearly one degree; and her mean distance, deduced from this, is found to be about 60 semidiameters of the earth, or 237,000 miles.

The sun being so much more distant than the moon, his parallax is much smaller, and cannot be discovered in the same manner. It is, indeed, so small a quantity, that considerable difficulty has been found in ascertaining it, and many attempts were made by various methods, up to a late period, before any satisfactory result was obtained. It cannot, in fact, be ascertained at all by direct observation of the sun, but only by means of the parallax of some other heavenly body which approaches nearer, and whose distance is known to bear a certain proportion to that of the sun. The body most successfully employed for this purpose is the planet Venus, and the occasion most favourable for the observation is the transit of this planet across the sun's disk. Before, however, entering into any explanation of this method, it is necessary to observe that the *relative* distances of all the planets from the sun are ascertained, independently of the parallax, by a calculation founded on the observed times of their periodical revolution round the sun. For it is a law of the planetary motions, ascertained by Kepler, and since proved by Newton, to be a necessary consequence of the force which retains the planets in their orbits, that *the squares of their periodic times are as the*

*cubes of their mean distances from the sun.** Thus, the periodic time of the earth, that is, the period of its revolution round the sun, being found by observation to be 365 days, and that of Venus 224 days, (neglecting fractions,) if we take the squares of these numbers, namely, 133225 and 50176, and the cube of 1, or 1000, or any other convenient number which we may assume to express the earth's mean distance from the sun, we have the terms of a statement in the rule of three, by working which in the usual way, we obtain a *fourth proportional* to these numbers, and the cube root of this is the number which will express the relative distance of Venus from the sun, in terms of the earth's assumed distance. The relative distances of all the planets from the sun, the earth's distance being assumed at 1000, are as follows:

Mercury	387	Jupiter	5202
Venus	723	Saturn	9540
Earth	1000	Uranus	19083
Mars	1523		

These proportional distances being thus ascertained, all that was wanted for determining the dimensions of the whole system, was to obtain the parallax, and by that means the absolute distance, of any one planet. This was long considered as the grand desideratum of astronomy, till the transits of Venus, which took place

* This is another of those laws which are known by the name of Kepler's laws, before referred to in p. 66, and of which more will be said hereafter.

in the years 1761 and 1769, afforded the opportunity of obtaining the earth's distance from the sun to a degree of exactness which could not be expected from any other method. Without entering into all the details of this observation, which would be foreign to the design of the present treatise, the general principles upon which it proceeds may be thus briefly explained.

Let E, Fig. 22, represent the earth, V, Venus, and S the Sun. To an observer at the centre of the earth, E, or on its surface at A in the same line of view, Venus will appear just entering upon the sun's disk at D, when to a spectator situated at B, 90 degrees westward of A, it will be eastward of the sun, in the direction of the line BVC. The angle EVB is the horizontal parallax of Venus, being the angle which the earth's semidiameter would subtend as seen from that planet; and EDB is, for a like reason, the horizontal parallax of the sun. The angle VBD, which is the measure of the apparent distance of Venus from the sun to the spectator at B, is equal to the difference of these two angles of parallax, (according to a well known property of triangles,*) and is found by observing how much later in absolute time the ingress of the planet upon the sun's disk is as seen at B, than as seen at A. From this angle, and the relative distances of the earth and Venus from the sun, already known by the means above mentioned, the horizontal parallax both of Venus

* See Euclid, Book I. Prop. 32.

and the sun may be found by calculation. The sun's parallax is thus ascertained to be about $8\frac{3}{5}$ seconds, and by computing upon these data, the dimensions of the triangle EDB, as in the case of the moon, the side ED, which is the earth's distance from the sun, is found to be about 95,000,000 miles. Hence the absolute distances of all the other planets are easily reckoned by means of the proportional distances already stated.

Knowing the distances of the sun and planets, we are enabled also to ascertain their magnitudes, by merely observing their apparent magnitudes: for the apparent size of any object diminishes as its distance increases. The mean apparent diameter of the sun is 32′ 2″; his distance 95,000,000 miles: with these data it is easy to calculate, by the rules of Trigonometry, what must be his real diameter, in order to appear of that size at that distance. Or we may ascertain the same from the sun's horizontal parallax, which, as before explained, is the angle under which the earth's semidiameter would appear, if seen from the sun. This angle being $8\frac{3}{5}$ seconds, the *entire* diameter of the earth as viewed from the sun, would appear under an angle twice as large, or of $17\frac{1}{5}$ seconds: and it has been already observed, that the sun's apparent diameter, as viewed from the earth, is 32 minutes 2 seconds, or 1922 seconds. Now the real diameters of objects seen at the same distance are proportional to their apparent diameters: therefore the sun's real diameter is to the earth's as 1922 to $17\frac{1}{5}$, or nearly as $111\frac{7}{10}$ to 1. Hence,

if the earth's mean diameter be estimated at 7911¼ miles, that of the sun will be 883,740. Their relative solid magnitudes are easily found from their relative diameters, by merely taking the cube of the latter; for spheres and all other regular solids are to each other, in respect of bulk, as the cubes of their diameters. Therefore the solid bulk of the sun is to that of the earth as 1,393,668, the cube of 111·7 to 1, the cube of 1. In a similar manner the diameters and solid bulk of the moon and planets may be deduced from their apparent diameters and their known distance.

The following table contains a summary of the most important particulars of the solar system, according to the latest and most approved estimates. It is recommended to the learner to commit it carefully to memory.

TABLE OF THE SOLAR SYSTEM.

Names.	Symbols.	Distance from the Sun in E. miles.	Diameter.	Annual revolution.	Diurnal rotation.	Inclination of orbits to the ecliptic.
Sun.......	☉	....	883,740	....	25*d.* 10*h.*	....
Mercury...	☿	37,000,000	3,224	87*d.* 23*h.*	*doubtful.*	7° 0′
Venus......	♀	68,000,000	7,687	224*d.* 16*h.*	23*h.* 21′	3° 23′
The Earth..	⊖	95,000,000	7,911¼	365*d.* 5*h.* 48′ 49″	23*h.* 56′	
Mars......	♂	144,000,000	4,189	1*yr.* 321*d.*	24*h.* 39′	1° 51′
Jupiter.....	♃	490,000,000	89,170	11*yr.* 315*d.*	9*h.* 55′	1° 18′
Saturn.....	♄	900,000,000	79,042	29*yr.* 161*d.*	10*h.* 16′	2° 29′
Uranus....	♅	1,800,000,000	35,112	83*yr.* 294*d.*		46′

In addition to the particulars comprised in the preceding table, the following are well worthy of a place in the memory.

	d.	h.	′	″
Sidereal year	365	6	9	12
Tropical year	365	5	48	49
Difference			20	23

Precession of the equinoxes, 50¼ seconds per annum, or 1 degree in 72 years.

Platonic year, or period of the entire revolution of the equinoxes	25,791 *years.*
Earth's circumference round the equator	24,892 *miles.*
Circumference round the poles......	24,855
Equatorial diameter	7923·6
Polar diameter..................	7899·88
Mean diameter..................	7911·74
Moon's mean distance from the earth.........................	237,000
Moon's diameter	2,180

	d.	h.	′	″
Synodical month...........	29	12	44	3
Periodical month	27	7	43	5
Lunar year, or 12 lunations..	354	8	48	36

Inclination of moon's orbit to the ecliptic 5° 9′

As, however, it is difficult for the imagination to form an adequate idea of these vast distances and magnitudes, it may serve to assist our conceptions to have them truly represented on a reduced scale. This

cannot well be done by any diagram on paper, for though the proportional sizes of the several bodies of the system, and the proportional dimensions of the planetary orbits, may be easily represented in separate plates and on different scales, yet to exhibit them all at one view on the same scale, would require a plate of such dimensions as could not well be furnished. The diagrams drawn on paper for the purpose of illustrating the phenomena of the heavens, are almost all of them extremely erroneous in point of proportion, and necessarily so, on account of the inconvenient space which would be required to represent the true proportions. Orreries are in general still more erroneous in this respect than diagrams, and the learner who forms his ideas of the solar system from these artificial representations, can hardly fail to be very widely misled. In order, then, to obviate such misapprehensions, and to form a more just conception of the relative magnitudes and distances of the several bodies in the system, let us take, as a representative of the earth, a small globe of one inch diameter, such as we find very commonly employed for this purpose in orreries, and let us consider what must be the dimensions of an orrery representing all the bodies of the solar system, and all their distances, according to the same proportion. The following table contains the corresponding diameters of the globes representing the sun and planets.

For the Sun, a globe of 9 feet 3 inches diameter.
For Mercury .... $\frac{2}{5}$ inch.
For Venus ....$\frac{19}{20}$ inch.
For the Earth .... 1 inch.
For the Moon .... $\frac{1}{4}$ inch.
For Mars............about $\frac{1}{2}$ inch.
For Jupiter ....$11\frac{1}{4}$ inches.
For Saturn .... .10 inches nearly.
For Uranus............... $4\frac{2}{5}$ inches.

The following will be the corresponding distances at which the globes representing the planets must be placed from that which represents the sun.

	Yards.
Mercury	128
Venus	239
The Earth......	331
Mars..........	503
Jupiter	1723, or nearly 1 mile.
Saturn	3161, or 1 mile 6 furlongs.
Uranus........	6358, or 3 miles 5 furlongs.

Moon's corresponding distance from the earth, about 30 inches.

CHAPTER XXIV.

OF THE CAUSES AND LAWS OF THE PLANETARY MOTIONS.

THE laws of the planetary motions, so far as they were discovered by Kepler, have already been adverted to in a former Chapter. (See p. 130.) That great philosopher, by a long series of minute and laborious observations, discovered the three following facts, which are known by the name of Kepler's laws: 1st. That the earth and all the other planets revolve round the sun in elliptical or oval orbits, having the sun in one of their foci: 2ndly, That a line joining the centre of the sun with the centre of any planet, (called the *radius vector*,) describes equal areas in equal times; and 3rdly, That the squares of the periodic times of the planets are as the cubes of their mean distances from the sun.* It was reserved, however, for the immortal Newton to establish these laws on the basis of mathematical demonstration, and to reduce them to one grand principle, which appears to pervade the universe—the principle of gravitation. It is impossible, without considerable know-

* The second of these facts is usually considered as the first of Kepler's laws, because it was first discovered. But this seems the most natural order of stating them.

ledge in mathematics, to follow out his profound investigations on this subject; but the following imperfect information may nevertheless be found of use to the young or unlearned reader.

It is a well known law in mechanical science, that, when a body is acted upon by two forces at the same time, it moves not in the direction of either, but takes an intermediate course between the two. Thus, let a ball, A, (Fig. 23.) be impelled by one force capable of driving it in a certain time to B, and let a second force be applied at the same instant, which singly would drive it to C, the course it will take, by the joint action of these forces, will be the diagonal AD. This is called the composition of forces, and is exemplified in the case of a vessel, which, being impelled in one direction by the wind, and in another direction by the current, takes a course between the two, but nearer the direction of the stronger force, if they happen to be unequal. If one of the forces remain uniform, while the other continually increases, the body upon which they act, will move in a curve, continually inclining nearer to the direction of the increasing force. Such is the case with bodies projected by any force, and falling to the ground by the power of gravitation. The projecting impulse by itself is capable of producing only a uniform motion, and even if the resistance of the air were withdrawn, would cause only equal quantities of motion in equal intervals of time. But gravitation, being a force which acts continually, produces a continual accession of motion in each successive portion of time, and the rate

of increase is ascertained to be as the series of uneven numbers 1, 3, 5, 7, 9, &c.; that is, if a falling body descend through a certain space in the first instant of its fall, in the second instant it will descend through three times that space, in the third instant through five times that space, in the fourth instant through seven times that space, and so on. This law which regulates the descent of bodies falling perpendicularly from any height, and when gravitation is the sole acting force, operates equally upon bodies projected, drawing them continually further and further from the line of projection, and bringing them to the ground, (if they are projected horizontally,) in the same time in which they would have fallen perpendicularly by their own weight. Thus let A, (Fig. 24,) be supposed the mouth of a gun, from which a bullet is discharged horizontally in the direction AL. If the projectile force, in the first moment, would carry it to B, while by gravitation it would fall to C, it will be found, at the end of that moment, at D, the opposite angle of the parallelogram ABDC. In the second moment the projectile force, (excluding the resistance of the air,) would carry it through the equal space BE, while gravitation would cause it to fall through the space CF, which is three times the first space AC; by the joint action of these forces, therefore, it will be found, at the end of the second moment, at G. In the third moment, while the projectile force would have carried it to H, and the power of gravitation would have caused it to fall through FI, which is five times AC, it will move from G to K; and in the

fourth moment, while one force would have borne it from H to L, and the other from I to M, which is seven times AC, it will arrive at N; thus describing the curve ADGKN in the same time in which it would have fallen perpendicularly from A to M. Precisely on the same principles may the motion of the planets be explained. They are acted upon, in like manner, by two forces; of which one draws them towards the sun, and the other tends to drive them off in a tangent to their orbits. The former is called the *centripetal* force, or the power of gravitation; the latter, the *centrifugal* or projectile force. Were these forces at all times exactly balanced, the planets would revolve in circles round the sun. If the power of gravitation prevailed for a continuance, the planets would fall to the sun, as the discharged bullet falls to the ground. Or if, on the other hand, the projectile force prevailed, and continued to prevail, they would fly off into the regions of boundless space. The fact is, that each of them prevails in its turn, and that, by a beautiful alternation, they so modify and control each other's influence, that neither of them can be augmented beyond a certain limit; and the effect of this is, that the planet alternately approaches to and recedes from the sun, revolving round him in that form of orbit, and according to those laws, which Kepler first discovered by observation, and which Newton demonstrated to be the necessary result of the laws of gravitation. When the planet is in perihelion, or at the point of its nearest approach to the

sun, both forces are at their maximum, but the *projectile* force predominates, and the planet therefore begins to recede. When it is in aphelion, or at the point of its greatest distance from the sun, both forces are at their minimum, but the *gravitating* force is then predominant, and the planet consequently begins to approach the sun. The reason of this will appear from Fig. 25, where S represents the sun, ADPB the elliptical orbit of a planet, of which P is the perihelion, and A the aphelion. When the planet is at B, the attracting power of the sun acts along the line BS, while the projectile force acts in the direction BC; and it is evident from the position of the lines, that the former force, in this situation, is, in some degree, opposed to the latter, and that the motion of the planet must consequently be retarded. But when the planet is at D, the attracting force draws it along the line DS, while the projectile force bears it along the line DE; and as the lines are partly in the same direction, the former force, instead of opposing, aids the latter, and the planet moves with accelerating speed. But the greater the speed of the planet's motion, the greater must be its tendency to fly off from its orbit, just as a stone at the end of a string pulls more and more strongly the more violently it is whirled. Hence it is that the projectile force gathers strength as the planet approaches its perihelion, P, till at that point it overcomes the gravitating power, though that power also is increased to its greatest intensity, by the planet's nearest approach to the centre of attraction.

But during the progress of the planet from perihelion to aphelion, its velocity being constantly retarded, as already shown, by the opposing tendency of the two forces, the projectile force is thereby continually weakened, till at A, the aphelion, it is so far reduced, that the gravitating force, though that also is then at its lowest ebb, becomes predominant, and the fugitive planet is brought back from its flight again to repeat the same unceasing round. Hence we see the reason of the fact already noticed, (see Chap. XI.) that the motion of the earth is faster in that part of its orbit which is nearest the sun, and slower in the remoter part. And mathematical reasoning has served to show, that the power which retains the planets in their orbits, is only a modification of that same power of gravitation, the effects of which we constantly witness in the descent of falling bodies, with this only difference, that in the one case the sun is the centre of attraction, and the attracting force is counterbalanced by the projectile, while, in the other case, the earth is the centre of attraction, and its influence is exerted without any counteraction. This great discovery is due to the exalted genius of Newton, who, setting out with the principle of gravitation, and with the law by which he had reason to believe it regulated, namely, that its force decreases as the squares of the distances from the centre of attraction increase, arrived by calculation at the same results at which Kepler had before arrived by observation; and demonstrated that all the laws of Kepler are the necessary consequences

of this principle combined with the projectile force. The same force which thus governs the motions of the primary planets, governs those of the secondary planets also; and its application to the moon was, in fact, the first step by which Newton was led to this discovery. The moon is known to be distant from the earth 60 of the earth's semidiameters, that is, 60 times as far from the centre as we are upon the surface. According, therefore, to the law already stated, by which the force of gravity decreases, the attraction of the earth upon the moon ought to be 3600 times less than it is upon falling bodies near the surface. Such is actually found to be the case; for by a calculation into which we cannot here enter, it is ascertained that the moon is drawn down from the rectilineal course, in which the projectile force would carry her, at the rate of 16 feet every *minute;* whereas falling bodies near the surface of the earth are drawn down at the rate of 16 feet per *second,* which, according to the law of falling bodies, gives 3600 times 16 feet for the amount of their fall in 60 seconds, or one minute.

CHAPTER XXV.

OF THE COMETS.

Besides the planets and their satellites, there are certain other bodies which seem to belong to the system, though they rarely make their appearance. They are distinguished from all the other heavenly bodies by a remarkable brush or tail of light which accompanies them, and from which they have derived their name of *Comets*. Little is known with certainty respecting these extraordinary bodies, but they are supposed to revolve round the sun by the same laws which govern the other planets, that is, in elliptical orbits, having the sun in one of the foci, with this peculiarity, however, that their orbits are very eccentric, so that though they approach very near to the sun in one part of their course, the fly off to an incalculable distance in the opposite part. The number of comets observed and recorded, with more or less accuracy, exceeds 350; but of these not one-third have been observed with such accuracy as to allow the elements of their orbits to be ascertained. The only comet which is known with any certainty to have returned, is that of 1682, which, conformably to the prediction of Dr. Halley, appeared in 1759, and which had been previously observed in 1531 and 1607, its period being about 76 years. The most remarkable of these bodies

was that which appeared in 1680. Its tail was of enormous length, extending over a space in the heavens nearly equal to one-fifth of its whole circumference; and it remained in sight for about four months. It was remarkable for its near approach to the sun, being, when nearest to it, no farther distant than 580,000 miles, which is but little more than half the sun's diameter. This comet descended from the upper regions of space, at a great angle with the orbit of the earth, between it and the orbit of Venus; and having passed round the sun at the distance above mentioned, ascended again. It appears that comets contain very little matter, and have but a very feeble action on other bodies: for in the year 1454 a comet is said to have eclipsed the moon, so that it must have been very near to the earth; yet it had no sensible effects. A comet also, in 1770, came very near to the satellites of Jupiter, but caused no derangement in the system.* Many conjectures have been hazarded respecting the use of these bodies, and the nature and cause of that train of light which accompanies them. But where nothing can be ascertained with certainty, it is better to acquiesce in an honest confession of ignorance.

* See Playfair's Outlines of Natural Philosophy, vol. ii. page 199.

CHAPTER XXVI.

OF THE FIXED STARS.

THE only bodies that now remain to be considered are the Fixed Stars, so called, as before observed, because they maintain invariably the same relative situation, and are only affected by that apparent diurnal motion which arises from the earth's rotation on its axis. The accuracy of modern observation has, indeed, detected some very slight changes both in the situation and appearance of some of the stars, and it is also said that new stars have occasionally appeared, and that some which were formerly observed are now no longer to be found. Some of the stars are likewise found to have a periodical increase and decrease of magnitude. But these changes are of too minute a nature to merit more particular notice in an elementary treatise, and can scarcely be said to alter the propriety of the epithet by which the stars are distinguished. The points chiefly to be attended to on this subject are, first, the number of the stars; next, their distance; and thirdly, their nature and use.

The number of stars visible at one view to the naked eye is estimated at one thousand; and the number in the whole starry sphere which may be seen without the aid of a telescope, comprehending all the stars from the first to the sixth magnitude, is about

3400. But when the eye is aided by the telescope, such multitudes of stars are discovered, that it is impossible to count them, or to assign any limits to their number. The milky way, that faintly luminous zone which encircles the heavens, and which appears to the naked eye like a track of light cloud, has been found by Dr. Herschel to be an aggregate of stars too distant to be distinguishable by the naked eye; and the same great astronomer has discovered not less than 2000 *nebulæ*, or luminous spots, which he has also ascertained to be clusters of stars.

Attempts have been repeatedly made to ascertain the distance of the stars, but hitherto without any satisfactory or accurate result. The method first followed for this purpose consisted in selecting some star of the first magnitude, and endeavouring to ascertain its *annual parallax*, that is, the change, if any, which takes place in its position in consequence of the earth's annual motion in its orbit. Let AB, Fig. 26, represent the earth's orbit, and C a distant star. The spectator being at A, the star will be seen in the direction AC; and at B, the star will be seen in the direction BC. In this case the angle ACB would be called the annual parallax of the star; and it is the same as the angle which the earth's orbit would subtend, if seen from the star. Now great pains have been taken by different astronomers to ascertain this angle; and the result of their labours is, either that the angle is not at all perceptible, or that, at the most, it cannot exceed one second. To all appearance the lines AC

and BC, directed to the star from opposite points of the earth's orbit, are parallel, as AD, BE; which shows that the diameter of the earth's orbit, though a distance of 190,000,000 miles, is but a mere point compared with the distance of the fixed stars. As some of the stars, which appear single to the naked eye, are found to be double when viewed through a telescope, and as it is with reason supposed that this appearance is owing to two stars being situated nearly in the same line of view, the one behind the other, hopes were entertained that, by a careful observation of such stars, some more satisfactory result might be obtained. For let AB, Fig. 27, represent the earth's orbit, and C D two stars, distant from one another, but appearing close together from the point A, because situated nearly in the same line of view; then it is evident, that if the earth's orbit, AB, bore any sensible proportion to the distances of the two stars, a spectator removed from A to B would see them no longer close together, but separated according to the amount of the angle CBD. This ingenious method, however, though tried with great care and assiduity by Dr. Herschel, has not yet led to any more satisfactory result than the former. It appears, in fine, from all the observations that have yet been made, that though the parallax of the fixed stars is completely undetermined, it can scarcely exceed a single second.

If, then, we suppose that the parallax of the nearest fixed star is one second, and that the mean distance

of the earth from the sun is 95,000,000 miles, we shall have a right-angled triangle, whose vertical angle is one second, its base 95,000,000 miles, and its side the distance of the star. This side, being calculated by the rules of Trigonometry, will be found to be upwards of 20 billions of miles—a distance through which light could not travel in less than three years. If the nearest star in the heavens is placed at such an immense distance from our system, what an immeasurable interval must be between us and those minute stars, whose light is scarcely visible with the most powerful telescope. Some of them, perhaps, are so remote, that the first beam of light which they sent forth at their creation, has not yet arrived within the limits of our system !*

Such being the immense distance of the fixed stars, it is evident that their nature and use can be subjects only of conjecture. But as they cannot shine, like the planets, by the borrowed light of our luminary, there is every reason to presume that they are themselves suns, equal or perhaps superior to our own in magnitude. And as it would be manifestly absurd to suppose that so many magnificent luminaries were created for no other end than merely to spangle our firmament, and to please our view with a useless glimmering, we are irresistibly led to the belief that

* "Fields of radiance, whose unfading light
Has travelled the profound six thousand years,
Nor yet arrives in sight of mortal things."

they are the centres of their own planetary systems, and that, consequently, the boundless realms of space are strewed with an incalculable number of systems not less grand and stupendous than that to which our earth belongs. And for what purpose can such countless worlds have been created, but to be the residence, like this earth, of beings formed to enjoy the bounties, or to understand and admire the perfections of the Great Supreme?

> "This gorgeous apparatus! this display!
> This ostentation of creative power!
> This theatre! What eye can take it in?
> By what divine enchantment was it raised
> For minds of the first magnitude to launch
> In endless speculation, and adore?
> *One* sun by day, by night *ten thousand* shine,
> And light us deep into the Deity:
> How boundless in magnificence and might!"

CHAPTER XXVII.

CONCLUDING REFLECTIONS.

The subject treated of in these pages, independently of its deep interest as a matter of mere curiosity, is so richly fraught with religious instruction, and so irresistibly leads the mind to religious contemplation, that it ought not to be dismissed without adverting to its suggestions of this nature. The grand display which Astronomy affords of the magnificence and order of creation, is such as cannot but impress every rightly constituted mind with a conviction that there must exist somewhere an Intelligence and a Power adequate to the production and superintendence of this vast system of things, and as much superior to man as these stupendous works are superior to the puny productions of human art and labour. The origin of the human race dates but a few centuries back; and can we suppose that there was no Intelligence previously existing in the wide circuit of this unbounded universe? By slow degrees, by long continued observations, and profound calculations, mankind have at length succeeded in ascertaining the true arrangement of the solar system, and the laws which govern the motions of the planetary bodies, so as to be able to predict with most unerring exactness their situations and appearances at any future moment; and

can we suppose that there was no Mind to which this arrangement and these laws were known, ere yet the human race had emerged from primeval barbarism, or issued from the womb of nothingness? While our imaginations range through the tracts of boundless space, and amidst the innumerable systems which are strewn around in such profusion, it is impossible to exclude from our minds the belief that *time* is as unlimited as *space* appears to be. The universe, viewed in its real magnitude, irresistibly forces upon the mind the conviction of *Eternity*, and the idea of Eternity, accompanied thus with that of worlds in ceaseless motion,—of worlds exhibiting, as we have reason to presume, the same inexhaustible powers of invention, the same unbounded diversity of being, which we witness in this scene of our own habitation, compels, not less forcibly, the belief of a creating and superintending Power, whose existence is commensurate therewith. It is impossible to believe that all the intelligence which exists in nature is confined to the limits of this little planet. And if other worlds contain intelligent inhabitants, it is reasonable to suppose, from that infinite variety which we every where observe in all the works of nature, that they are distinguished by various degrees of intelligence, and that some may be as much superior to man as man is superior to the brutes. When once, however, this idea is admitted, we can assign no limits to the scale of progression; and yet, the higher we raise our ideas of *finite* excellence, the greater appears the necessity of supposing *some being*

superior to all; for no being, however exalted, whose existence has had a commencement, can possibly have himself originated that existence; and no being whose habitation is confined to one planet, or one sun, or one system, can have powers adequate to the comprehension and superintendence of universal nature. There is a unity of design in the system of nature, which plainly indicates the existence and operation of one great directing Mind. The same power which rolls this vast and ponderous globe on which we tread, in its annual circuit round the sun, which controls its impetuous flight, and causes it to fulfil, with such unerring regularity, its wonted course, must direct the motion of all those other orbs which revolve by the same laws round the same central luminary. And if we admit the existence of an intelligent power adequate to the government of one planetary system, there is no difficulty in supposing that same power to extend to all those other systems which we see scattered through the immensity of space. We have spoken, indeed, of certain forces, of a projectile impulse, and a power of gravitation, which, by their combination, according to the laws of mechanics, produce the planetary motions. But who does not see that these are merely convenient names for expressing the *mode of agency* of some hidden cause? To suppose that inert masses of senseless matter have in themselves this double tendency, gravitating towards a centre in one direction, and attempting to fly off in another direction, is an absurdity too gross to be entertained for a moment. The power

which launched these stupendous bodies into motion, and which still continually bends and controls their flight, can be no other than the power of God. This conclusion will be yet further strengthened, if we consider how nicely the whole system is balanced,—how slight a deviation from its established laws would throw the whole machine into the most fatal confusion, and yet how unerringly it performs its appointed movements. Were the velocity of any planet's motion increased beyond a certain limit, the attractive force would be insufficient to retain it in its orbit, and it would fly off into the immensity of space, never to return within the limits of the system. On the other hand, were its velocity diminished beyond a certain limit, the attractive force would overcome the projectile, and the planet would fall to the sun. Now one or the other of these effects must have taken place, if the force of gravitation had varied by any other law than that which we actually find to prevail; for it can be shown mathematically that, if this force had varied inversely as the cube of the distance, or by any other law than the inverse square, the planetary orbits could not have continued permanent, but such disorders would have ensued in the system, as must inevitably have brought on sooner or later its total destruction. The system, even as it is actually constituted, is subject to certain disturbances and irregularities, in consequence of the mutual influence of the planets upon each other; but in every case there is a certain limit beyond which these deviations never pass.

Thus "the planes of the orbits of the planets are subject to a variation of situation; but, after certain periods, they return to the positions from whence they departed. The inclinations of their orbits to the ecliptic are also subject to a change; but this change is confined to small limits, and in a stated period each orbit returns to that inclination from which it set off. The figure of the earth's orbit is approaching towards that of a circle; but it will afterwards gradually recede from that figure, and return to its original form. The like circumstance takes place in the figures of the orbits of the other planets. It has been found by observation, that the mean motion of the moon is increasing; but after a certain period it will decrease by the same steps, and no apprehensions need be entertained for the stability of that part of the system. The obliquity of the ecliptic is diminishing; and hence it has been supposed that seed-time and harvest, summer and winter, might hereafter cease; but it will afterwards increase, and return to its former state; and the variation will be confined to such limits, that the seasons will never be sensibly affected by it. All the planets move in the same direction in their orbits, and this is essential to the stability of the system; otherwise the disturbances would not have had their regular periods of increase and decrease, as at present, but the irregularities, by increasing, would have brought on its destruction. Hence we find no confusion of motion, which, under any other law of gravitation, would have taken place; nothing anomalous;

no constant increase of irregularity, by which, in the course of time, the system might be destroyed. There is a *mean* situation, about which the system oscillates through very small spaces; hence, every thing returns to that state from which it departed, and thus the whole is preserved from falling into ruin."* To this striking testimony of an eminent philosopher, whose profound knowledge of astronomy entitles his sentiments to the highest respect, I beg leave to subjoin, in conclusion, the following sentence from the pen of one not less competent to judge upon the subject: "By the most simple law, the diminution of gravity as the square of the distance increases, the planets are not only retained in their orbits, when whirling round a central sun, but an eternal stability is insured to the solar system. The little derangements which affect the motions of the heavenly bodies are apparent only to the eye of the astronomer; and even these, after reaching a certain limit, gradually diminish, till the system, regaining its balance, returns to that state of harmony and order which preceded the commencement of these secular inequalities. Even amidst the changes and inequalities of the system, the general harmony is always apparent; and those partial and temporary derangements which, to vulgar

* Vince's Confutation of Atheism, from the Laws and Constitution of the Heavenly Bodies, in Four Discourses preached before the University of Cambridge, p. 92.

minds, may seem to indicate a progressive decay, serve only to evince the permanence and stability of the whole. In the contemplation of such a scene, every unperverted mind must be struck with that astonishing wisdom which framed the various parts of the universe, and bound them together by one simple law."*

* Brewster's Edition of Ferguson's Astronomy, vol. i. p. 71, note 3, by the Editor.

QUESTIONS FOR EXAMINATION.

INTRODUCTION.

1. How is Astronomy defined?
2. What is the derivation and meaning of the term?
3. Why is it an interesting study?
4. On what ground may it be recommended, independently of its direct utility?
5. To what important art is it subservient?
6. How is it connected with Geography?
7. How has it proved useful to the historian?
8. What errors has it served to dispel?
9. What is its highest and most important use?
10. What is the observation of the Psalmist on this subject?
11. What is the sentiment of a modern poet?

CHAP. I.

1. What is the first step in the study of Astronomy?
2. What are the appearances which first present themselves to our notice in the heavens, and what inferences do we at once draw from them?
3. What do we observe on looking towards the south?
4. What do we observe on looking towards the north?
5. What remarkable point do we find there, and how is its situation marked?

6. What change takes place in the situation of the pole, when we travel northwards or southwards?
7. What should we observe if we travelled continually southwards?
8. What, then, is the appearance of the whole starry heavens, and how is it artificially represented?
9. In what respects does the celestial globe differ from the real sphere of the heavens?
10. What is represented by the wooden circle which surrounds the globe?
11. What is the derivation and meaning of the word Horizon?
12. What is meant by the terms Zenith and Nadir?
13. How may we represent on the celestial globe the aspect and motion of the heavens, as seen at any place?
14. What are the use and probable origin of the various figures which are drawn upon the surface of the globe?
15. Mention and point out on the globe some of the more remarkable constellations.
16. How are the stars further distinguished and classified?
17. What method is employed for designating particular stars, and by whom was it invented?

CHAP. II.

1. What are the chief points of the horizon, and how are we led to remark them?
2. What is the first great circle which the ancient astronomers imagined to be drawn upon the sphere, and how is it situated?
3. What is the next great circle, and how is it situated?
4. Why is a star said to *culminate*, when it crosses the meridian?

5 What is the derivation of the term *meridian*?
6. What is a meridian line, and how may it be drawn?
7. What fact proves that the Egyptians were acquainted with the method of drawing a meridian line?
8. How are these two great circles divided, and for what purpose?
9. What is the probable origin of this division?

CHAP. III.

1. What is meant by the Altitude of a heavenly body, and how is it ascertained?
2. What is a Vertical Circle?
3. What instrument is used to represent any vertical circle, and to measure altitudes on the celestial globe?
4. Describe, by means of Fig. 1, the method of measuring the altitude of a heavenly body in the celestial sphere itself.
5. What is meant by the Azimuth of a heavenly body?
6. What is meant by Amplitude?
7. Show how azimuth and amplitude are measured on the globe.

CHAP. IV.

1. What was the first idea of mankind respecting the figure of the earth?
2. To what period can the doctrine of its spherical figure be traced back?
3. What observations are irreconcilable with the supposition of the earth being a plane, and how is this shown by Fig. 2?
4. Show by Fig. 3. how these appearances may be explained, on the supposition of the earth being a sphere.

5. How has the roundness of the earth been proved experimentally?
6. Who first attempted the circumnavigation of the globe, and what is the history of that attempt?
7. How is the roundness of the earth sometimes made evident to the senses, and what striking instance of this is adduced from the Journal of Captain Basil Hall? (See the note in page 20.)
8. How is the same truth confirmed by eclipses of the moon?
9. How may the circumference of the earth be ascertained?
10. By whom was the first attempt made to measure the earth, and what was his mode of proceeding?
11. Who first solved this problem satisfactorily; how did he proceed; and what was the result which he obtained?
12. What is the circumference of the earth, according to later and more accurate measurements?
13. What is the earth's diameter?
14. Is the earth a perfect sphere?
15. Who first conjectured the earth's spheroidal form, and on what grounds?
16. How was Sir I. Newton's opinion confirmed?
17. What was the difference between the degree measured in Lapland, and that measured in South America? (See the note in page 23.)
18. Explain, by means of Fig. 4, how this difference must necessarily arise from the spheroidal figure of the earth.
19. How much does the equatorial exceed the polar diameter?

CHAP. V.

1. What was formerly the universal belief respecting the apparent diurnal revolution of the heavens?
2. Does history inform us who first advanced the doctrine of the earth's diurnal motion?
3. What considerations led astronomers to the belief of this fact?
4. At what rate must the sun move, if it really revolves round the earth?
5. How is it shown to be impossible for a larger body to revolve round a smaller which is stationary?
6. Why is it no objection to this doctrine, that we are not sensible of the earth's motion?
7. What other objection has been urged with great confidence against this doctrine, and how is it answered?

CHAP. VI.

1. How must the terrestrial globe be considered in connexion with the celestial?
2. What is observed of the wooden circle on the terrestrial globe, and how should it be considered?
3. Explain the distinction between the sensible and the rational horizon.
4. Why may they be considered the same as respects the heavens, and how is this shown by Fig. 5?
5. What is observed of the equator of the earth?
6. What is Latitude, and how is it estimated?
7. What is the utmost extreme of latitude?
8. What are Parallels of Latitude?
9. What are those lines called which are drawn at right angles to the equator, and extended to each pole, and what is their use?

10. How many meridians are drawn upon the terrestrial globe, and why?
11. How may the difference of time be estimated by means of these meridians?
12. What are the respective effects of travelling eastward and westward round the earth?
13. What is Longitude, and where does the reckoning of longitude commence?
14. What does the brazen circle in which the globe is hung, represent; and what is its use?
15. How is the longitude of places ascertained on the globe?
16. What is a Right Sphere, and where is that aspect of the heavens presented?
17. What is a Parallel Sphere, and where is it seen?
18. What is an Oblique Sphere, and where seen?
19. What determines the elevation of the pole at any place?
20. How may the elevation of the equator be found?
21. What is the simplest and easiest method of ascertaining the latitude of any place by celestial observations?
22. What is the method, when greater accuracy is required?
23. How is longitude ascertained?

[It is thought needless to introduce questions on the Problems, as they so easily suggest their own questions. It is more convenient, also, for the teacher or learner to vary such questions at his own pleasure, and to adapt them to the present time and place.]

CHAP. VII.

1. Is the diurnal motion of the heavenly bodies from east to west the only motion which we may observe?
2. What additional and peculiar motion has the moon?

3. How does it appear that the sun also changes his place in the heavens?
4. What is there further to be observed in this motion of the sun towards the east?
5. Why is he known to be on the equator on the 21st of March; and what is this period called?
6. What is his position on the 21st of June; and what is that period called?
7. When is he again upon the equator?
8. When is he at the greatest distance south of the equator?
9. What term is employed to express the sun's distance northward or southward from the equator?
10. What was probably the first great problem which engaged the attention and exercised the ingenuity of astronomers?
11. What rendered it a matter of much difficulty to ascertain the sun's path among the stars?
12. Have we any records of this discovery?
13. How may we suppose the discovery to have been accomplished?
14. What is the sun's path called, and how is it divided?
15. Repeat the signs of the ecliptic, and state the respective days on which the sun enters them.
16. Write their several symbols.
17. What are the *ascending*, and what the *descending* signs, and why are they called?
18. How is each sign subdivided?
19. What are those circles called which mark the extreme limits of the sun's declination; and what is the meaning of the name?
20. What other bodies besides the sun and moon have motions peculiar to themselves?

21. Describe the motions of the planets.
22. Why are they termed *Planets*?
23. How many of them are visible by the naked eye, and what are their names?
24. Within what limits are their wanderings confined?
25. What name has been given to the region of the planetary motions, and what is the meaning of the name?

CHAP. VIII.

1. How did the ancients account for these additional and peculiar motions of the sun, moon, and planets?
2. In what order did they suppose the spheres to be placed?
3. Under whose name was this system of Astronomy established?
4. What singular and fanciful notion did Pythagoras add to this doctrine?
5. What peculiar musical phraseology arose from this doctrine?
6. What flattering honour did the disciples of Pythagoras ascribe to their master in reference to this doctrine?
7. What remark is said to have been made by Alphonso, king of Castile, on the structure of the world according to the Ptolemæan system?
8. What system of Astronomy is now universally received?
9. Who was Copernicus, and when did he live?
10. When, and by whom, is the same system said to have been previously taught?
11. What is the order of the Copernican system?
12. Show by Fig. 6. how the sun's apparent motion may be reconciled with this system.

13. What new and more accurate notion may hence be formed of the Ecliptic?

CHAP. IX.

1. What causes the obliquity of the sun's apparent path in the heavens?
2. What would be the effect, if the earth's axis were perpendicular to the plane of its orbit, as represented in Fig. 7?
3. How much is the earth's axis inclined from the perpendicular position, and what is the effect of this, as shown by Fig. 8?
4. What is the position of the earth with respect to the sun in summer; where is the sun then vertical; and why have we then longer days than nights?
5. Why is it that there is no night at that time within the north polar circle?
6. What is the position of the earth in winter; where is the sun then vertical; and why are the nights then longer than the days?
7. What is the position of the earth at the equinoxes, and why are the day and night then equal in length?
8. In what part of the earth are the days and nights always equal, and why?
9. What is the direction of the earth's revolution?
10. In what time is it performed?
11. What is the purpose of the Tropics?
12. What is that region called which they include?
13. What is the extent, and what the characteristic of that region?
14. What is the purpose or use of the Arctic and Antarctic Circles?
15. What name is given to those regions which they in-

clude, and what is the characteristic of those regions?

16. How are the remaining regions of the earth denominated, and what is their breadth?

CHAP. X.

Questions preparatory to the Problems.

1. What is observed of the Ecliptic, as drawn upon the terrestrial globe?
2. What is the use of the scale called the Analemma?
3. What is the sun's true path over the surface of the earth?
4. What is the meaning of the terms Latitude and Longitude, as applied to the celestial globe? p. 56.
5. What is meant by the *right ascension* of a heavenly body? p. 57.
6. What is represented by the wooden circle in the Problems on the terrestrial globe? p. 59.

CHAP. XI.

1. How many days are there between the Vernal and the Autumnal Equinox?
2. How many between the Autumnal and the Vernal, and what is the difference?
3. Show, by means of Fig. 9, the cause of this difference.
4. To whom are we indebted for this discovery?
5. Does the earth move always with the same velocity?
6. In what part of its orbit does it move the fastest?
7. When is the earth nearest the sun?
8. Show by the Figure what is meant by the eccentricity of the earth's orbit, and state the amount of it in English miles.

9. How much nearer is the earth to the sun in winter than in summer?
10. By what observations is this fact confirmed?
11. How then is the greater heat of the weather in summer to be accounted for?
12. By what remarkable law is the earth's motion in its orbit regulated?
13. Illustrate this by Fig. 10.
14. Is this law peculiar to the earth?
15. By whom was it discovered?
16. What is meant by the terms Perihelion and Aphelion?
17. What is the line of the Apsides?
18. What is the place of the earth's Aphelion?
19. What is meant by the earth's mean distance from the sun, and at what number of miles is it estimated?

CHAP. XII.

1. What is a solar day, and how long is it?
2. What is a sidereal day, and how long is it?
3. Why is the solar day longer than the sidereal?
4. Why is the sidereal day so called?
5. Is the solar day always of the same length?
6. What is the first cause of the unequal length of the solar days?
7. How is the length of the day affected when the earth moves faster than usual?
8. What is the second cause?
9. How is the length of the solar days affected when the sun is passing through Pisces and Aries, and what is the reason of this?
10. How is their length affected, when the sun is passing through Gemini and Cancer, and what is the reason?
11. What is meant by *mean time*?

12. What by *apparent time?*
13. What is the *equation of time?*
14. How often, and at what times, would the clock and sun agree, according to the first of the causes above mentioned?
15. How often, and at what times, would they agree, according to the other cause?
16. How are equation tables constructed?
17. On what days do the clock and sun actually agree?
18. What is the utmost difference between them?

CHAP. XIII.

1. What circumstance occasioned for a long time great perplexity in the computation of the year?
2. What people first attempted to determine the length of the year, and what was their first estimate?
3. What was their next estimate?
4. What error arose from reckoning the year at 365 days only?
5. Who undertook to rectify this error, and how was it done?
6. What name did the Romans give to that year in which the additional day was introduced, and why?
7. What is it now called, and why?
8. By what name is this calendar distinguished?
9. What is the error of the Julian calendar?
10. Who undertook a further reformation of the calendar?
11. What was the amount of the error in the time of Gregory?
12. How was this error rectified, and what plan was adopted for preventing its recurrence?
13. By what name is this new reckoning distinguished?
14. In what countries was the Gregorian calendar at first received?

15. When was it first adopted in this country?
16. What was then the amount of the error, and how was it rectified?

CHAP. XIV.

1. What may be observed respecting the Signs of the Ecliptic, on inspecting a celestial globe?
2. What is this owing to?
3. How is this motion of the equinoctial points denominated?
4. Illustrate the Precession of the Equinoxes by means of the celestial globe.
5. At what rate do the equinoctial points recede?
6. What time will be required for their complete revolution?
7. What is meant by the *Tropical Year*, and how long is it?
8. What by the *Sidereal Year*, and how long is it?
9. How does the precession of the equinoxes affect the situation of the stars?
10. How far are the signs of the ecliptic now removed from the constellations from which they take their names?
11. How has Sir I. Newton availed himself of the precession of the equinoxes for correcting ancient chronology?
12. Of what particular event has he by this means ascertained the date?

CHAP. XV.

1. Why did the moon attract at a very early period the attention of mankind?
2. How were the periods of new and full moon anciently celebrated?

3. What division of time arose from the revolution and changes of the moon?
4. What is now known respecting the moon?
5. What is meant by the Phases of the moon, and what may be inferred from them?
6. In what situation is the moon when she is invisible?
7. What is her situation when she appears a half moon?
8. What is her situation at the full?
9. What is the length of the period between one new moon and the following?
10. What is this period called?
11. What is meant by the Periodical Month, and how long is it?
12. Explain, by means of Fig. 12, the reason of this difference.
13. What is meant by the term *Conjunction?*
14. ——————————— *Opposition?*
15. ——————————— *Quadrature?*
16. Write the several symbols by which these situations are denoted.
17. What is the line of the Syzygies?
18. What is the form of the moon's orbit?
19. Is the eccentricity of the orbit always the same?
20. How is it placed with respect to the earth's orbit, and how is this illustrated by Fig. 13?
21. What are the moon's *Nodes*, and how are they distinguished?
22. What alteration takes place in their position?
23. In what time does the moon revolve upon her axis, and what is the effect of this?
24. What is meant by the moon's *libration in longitude*, and how is it occasioned?
25. What is meant by the *libration in latitude*, and what is the cause of it?

26. What is the moon's distance from the earth?
27. What is observed respecting the moon's path in space, and how is this illustrated?
28. What is the moon's diameter, and what proportion does her solid bulk bear to that of the earth?
29. What appearance does the moon present, when viewed through a telescope?
30. What appearances most decisively prove the existence of mountains and cavities in the moon?
31. What is the estimated height of the lunar mountains?
32. Is there reason to believe that the moon's surface is diversified with land and water, like the surface of the earth?

CHAP. XVII.

1. How were Eclipses formerly regarded?
2. How are eclipses of the sun occasioned, and in what situation of the moon do they happen?
3. How are eclipses of the moon occasioned, and in what situation of the moon do they happen?
4. Why is there not an eclipse both of the sun and moon every month?
5. Explain this more fully by means of Fig. 14, and show in what circumstances the conjunction or opposition of the moon must take place, in order to occasion an eclipse.
6. What is the limit of the moon's distance from her node in *solar* eclipses?
7. What is the limit of the moon's distance from the node in *lunar* eclipses?
8. Which kind of eclipses happen most frequently, and why?
9. Which kind are most frequently observed, and why?

10. Show, by means of Fig. 15, how a *total* eclipse of the sun is occasioned.
11. What is the utmost breadth of the moon's proper shadow, when it falls upon the earth?
12. Show how an *annular* eclipse is occasioned.
13. Under what circumstances does a solar eclipse appear *partial*?
14. What is the utmost breadth of the moon's penumbra?
15. What is the usual number of eclipses in the year, and why?
16. What is the smallest possible number of eclipses in the year, and why must they be solar eclipses?
17. How may six eclipses happen within the year, in the case when each node is presented only once to the sun, and of what kind will they be?
18. How may three eclipses of each luminary be produced in the course of the year?
19. What is the greatest possible number of eclipses which the year can comprehend, and why?

CHAP. XVIII.

1. What is the chief agent in producing the Tides?
2. By whom was the cause of the tides first clearly explained?
3. Repeat the particulars of his explanation. See Fig. 16.
4. At what intervals do the tides succeed each other, and why?
5. Does the time of high water coincide with the time of the moon's coming to the meridian?
6. Why is the sun's influence upon the tides less than the moon's?
7. What are the respective forces of the sun and moon, according to Sir I. Newton's estimate?

8. What circumstances occasion the spring and neap tides, and how often do they happen?
9. Why are the spring tides themselves not always of the same height?
10. At what period of the year do the highest tides happen, and why?
11. What circumstances affect very much both the height of the tides, and the time of their happening?
12. In what kind of places do the tides rise highest, and how is this exemplified?
13. Why are the tides scarcely perceptible in the Baltic and Mediterranean?
14. Why do the tides happen at various hours in different places?
15. What is the progress of the tides along the coasts of Great Britain and Ireland?
16. What remarkable fact is stated respecting the tides in the river Amazons?

CHAP. XIX.

1. At what rate does the moon move towards the east?
2. How much later upon an average does she rise every successive day?
3. In what parts of the world is this uniformly the difference in her time of rising?
4. What variation from this rule takes place in parts of considerable latitude?
5. To what is this owing?
6. How often in the year do these risings of the moon at nearly the same hour take place?
7. When is this phenomenon most remarked, and why?

CHAP. XX.

1. What is the sun's diameter?
2. How much does it exceed the earth in solid bulk?
3. In what time does it revolve upon its axis?
4. How has this fact been ascertained?
5. What is the *apparent* time of the revolution of the spots, and why is it longer than the *real* time?
6. How is the sun's axis placed with respect to the earth's orbit?
7. What is Dr. Herschel's opinion respecting the solar spots?

CHAP. XXI.

1. What are the inferior planets, and why are they so called?
2. How does it appear that their orbits are included within that of the earth?
3. What is meant by their greatest elongation?
4. Describe their apparent motions in the heavens.
5. Explain these motions, by means of Fig. 17.
6. What is meant by the terms inferior and superior conjunction?
7. What is the apparent form of an inferior planet, when viewed through a telescope?
8. What planet is nearest to the sun?
9. What is Mercury's greatest elongation?
10. What is his distance from the sun?
11. What is the time of his periodical revolution?
12. What is his diameter?
13. What is his magnitude compared with the earth?
14. How is his orbit placed with respect to the earth's orbit?

15. What is the place of his ascending node?
16. What is meant by a transit of Mercury, and under what circumstances does it happen?
17. What proportion of light and heat does he receive from the sun?
18. What is the appearance of Venus?
19. What is her greatest elongation?
20. By what different names was she known to the ancients?
21. What is the time of her apparent revolution round the sun?
22. What is the time of her actual revolution, and what is the reason of this difference?
23. What is her distance from the sun?
24. Her diameter?
25. What is the time of her diurnal rotation?
26. How is her orbit placed with respect to the earth's?

CHAP. XXII.

1. What is meant by the term Superior Planets?
2. What fact proves that their orbits include that of the earth?
3. What are their apparent motions?
4. Explain these motions by means of Fig. 19.
5. How many superior planets are there, and what are their names?
6. How is Mars distinguished from all the other planets?
7. What is supposed to be the cause of this appearance?
8. When does he appear largest, and why?
9. What is his distance from the sun?
10. His diameter?
11. In what time does he revolve on his axis?

12. In what time does he revolve round the sun?
13. How is his orbit placed with respect to the earth's orbit?
14. How is his axis placed with respect to his own orbit?
15. What are the names of the four lately discovered planets which revolve between Mars and Jupiter?
16. How long have they been discovered?
17. What are the respective diameters of Ceres and Pallas?
18. In what respect are they remarkable?
19. What is the appearance of Jupiter?
20. What is his diameter?
21. What is his distance from the sun, and the time of his annual revolution?
22. What is the time of his diurnal rotation?
23. What is the consequence of this rapid motion on his axis?
24. How is his axis placed with respect to his orbit?
25. What is the inclination of his orbit to the plane of the ecliptic?
26. What remarkable appearance does he present, when seen through a telescope?
27. How many satellites has Jupiter?
28. By whom, and when, were these satellites discovered?
29. What important purpose do their eclipses serve?
30. In what way is the longitude of a place found by means of these eclipses?
31. Why is this method not much used at sea?
32. What important fact has been ascertained by means of these eclipses?
33. What was formerly believed respecting the motion of light?
34. What difference is found in the times at which these eclipses are observed?
35. What is inferred from this?

36. What is the velocity of light? (See the note, p. 121.)
37. What is the distance of Saturn from the sun, and the time of his periodic revolution?
38. What is his diameter, and his bulk compared with the earth?
39. In what time does he revolve on his axis?
40. What is the inclination of his orbit to the plane of the ecliptic, and the place of the ascending node?
41. What singular appearance does this planet present when viewed through a telescope?
42. What are the dimensions of these rings?
43. In what respects does Saturn resemble Jupiter?
44. By how many satellites is Saturn attended, and how do they revolve round him?
45. What is the most remote planet of the system, and when and by whom was it discovered?
46. What different names have been given to it?
47. What is its distance from the sun, and the time of its periodic revolution?
48. What is its diameter, and its relative magnitude?
49. How much is its orbit inclined to the plane of the ecliptic?
50. How many satellites attend this planet, and how are their orbits placed?
51. What is meant by the *Heliocentric Longitude* of a planet?
52. What is meant by *Geocentric Longitude*?

CHAP. XXIII.

1. How may the distance of an inaccessible object be measured?
2. What is the base employed in ascertaining the distances of the heavenly bodies?

3. What is meant by the *Parallax* of a heavenly body, and what is the import of the term?
4. Illustrate this by Fig. 21.
5. What is the effect of parallax?
6. In what situation of a heavenly body is the parallax greatest, and where is it least?
7. Which of the heavenly bodies has the greatest parallax, and why?
8. Explain by Fig. 21. the method of ascertaining the moon's horizontal parallax, and of calculating by that means her distance.
9. By what means is the sun's parallax ascertained?
10. How are the relative distances of the planets known, independently of the parallax?
11. Explain by Fig. 22. the method of determining the sun's parallax by the transit of Venus.
12. How may the magnitudes of the heavenly bodies be found, when their distances are known?

CHAP. XXIV.

1. What are the three laws of the planetary motions which are known by the name of *Kepler's Laws*?
2. By whom were these laws further explained, and to what great principle were they reduced?
3. Explain by Fig. 23. what is meant by *the composition of forces*.
4. How is the effect varied when one of the acting forces continually increases?
5. How does the force of gravitation act upon falling bodies?
6. Explain by Fig. 24. the effect of this law in the case of a body projected horizontally.

7. By what two forces are the planets acted upon, and how are these forces denominated?
8. What would be the effect, if these forces were always exactly balanced?
9. What would be the effect, if either of them prevailed for a continuance?
10. Explain by Fig. 25. in what manner they modify and control each other's influence.
11. By what law does the force of gravitation decrease?
12. What, then, is the force of the earth's attraction upon the moon?
13. How does it appear that the force which retains the moon in her orbit is the same with that which draws down falling bodies to the earth?

CHAP. XXV.

1. How are comets distinguished from all the other heavenly bodies?
2. In what manner do they revolve round the sun?
3. What number of comets have been observed and recorded?
4. What is the only comet whose motions and times of appearance are known by calculation?
5. What comet was the most remarkable for its size, of all upon record, and what particulars are mentioned respecting it?
6. How does it appear that comets contain very little matter?

CHAP. XXVI.

1. Why are the fixed stars so called, and with what limitations must the name be understood?
2. What number of stars is visible to the naked eye at one view?

3. What is the number in the whole starry sphere, that may be seen without the aid of a telescope?
4. What does the telescope enable us to discover respecting the number of the stars?
5. What remarkable discoveries have been made on this subject by Dr. Herschel?
6. What is meant by the *annual parallax* of a star, (see Fig. 26.) and with what success has the attempt been made to ascertain it?
7. Why was it thought that *double stars* might afford a better means of solving this problem, and with what success has this method been attempted? (See Fig. 27.)
8. Supposing the parallax of the nearest fixed star to be one second, what must be its distance?
9. What time would be required for light to travel that distance?
10. What conjectures may reasonably be formed respecting the nature and use of the stars?

THE END.

LIVERPOOL:
PRINTED BY ROCKLIFF AND DUCKWORTH.

Lately Published by the same Author,

SYSTEMATIC MORALITY,

OR

A TREATISE

ON THE

THEORY AND PRACTICE OF HUMAN DUTY,

ON THE

GROUNDS OF NATURAL RELIGION.

LONDON:

Printed for Rowland Hunter, St. Paul's Church Yard, and
Sold by G. & J. Robinson and W. Grapel, Liverpool.

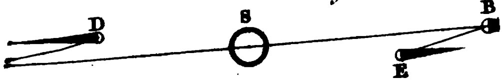


Fig. 14.

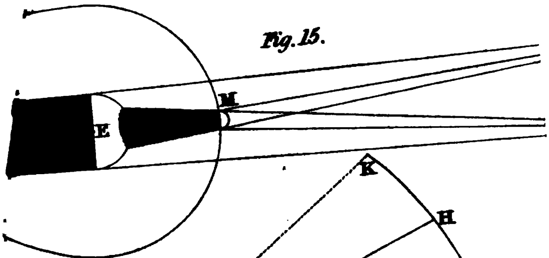
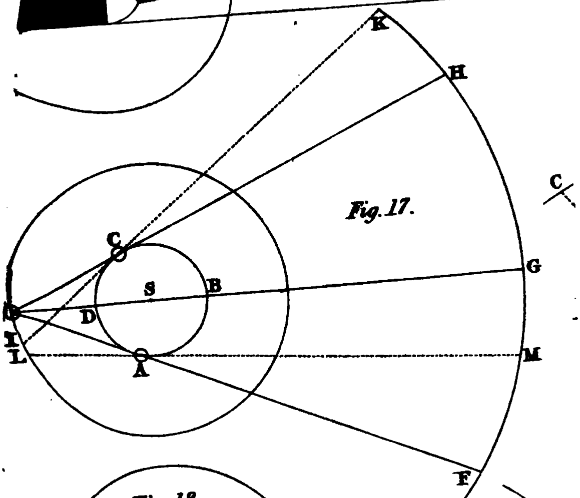


Fig. 15.



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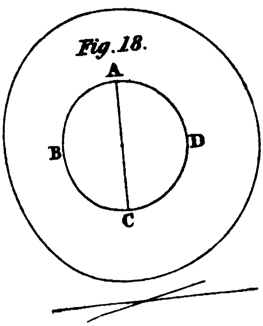

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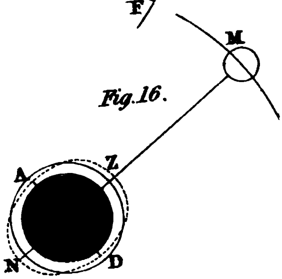
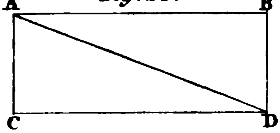
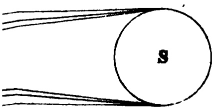


Fig. 16.

Fig. 23.





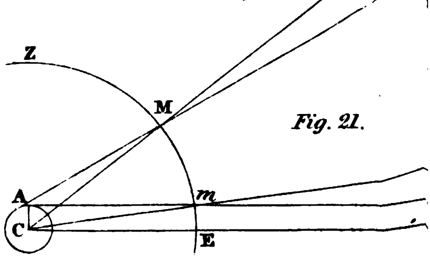
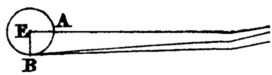


Fig. 21.



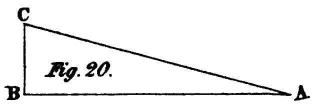


Fig. 20.

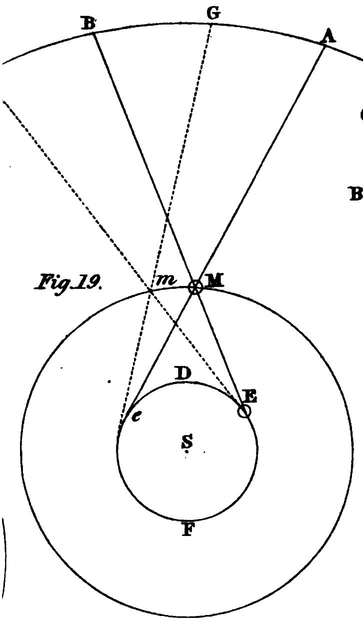


Fig. 19.

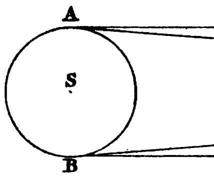


Fig. 26.

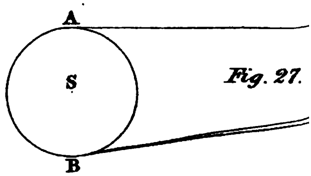


Fig. 27.